Imaginative Play with Blended Reality Characters

David Yann Robert

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning on June 2011, in partial fulfillment of the requirements for the degree of Master of Science in Media Arts and Sciences at the Massachusetts Institute of Technology

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Abstract

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 technical underpinnings of its unique blended physical and digital play context and the evaluation of its impact on children's play are the contents of this thesis.

A play test study with thirty-four children aged three and a half to seven was 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 showed 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.

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Imaginative Play with Blended Reality Characters

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This thesis is dedicated to Ms. Huyen Thi, my grandmother, an extraordinary educator and lifelong learner, "Nothing to repeat."
Imaginative Play with Blended Reality Characters
Prologue

This thesis began with a simple question I asked myself while working as an animator on feature films: what if I could animate off the screen? I soon began to wonder what that future might look like and began taking steps towards making that dream a reality. Having been involved in the very early stages of creating 3D animated feature films for 20th Century Fox and then moving into a creative research and development role to eventually joining the team of a two-time Academy Award winning software team pioneering the use of procedural animation in motion pictures, I had witnessed many important yet incremental changes over the years. I began to deeply consider what might lead towards a fundamental change in experiencing media, a paradigm shift that would enable entirely new media experiences. The promise of 3D movies with images that could leap off the screen was beginning to take form, yet I still yearned for an interactive experience of characters that you could actually touch. It soon occurred to me that the future of animation must be in robotics.

By researching the world’s robot labs and learning about the field of human-robot-interaction (HRI), I came in contact with the ground-breaking work of Dr. Cynthia Breazeal and her Robotic Life Group, now Personal Robots Group at the MIT Media Lab (a salon des refusées as Nicholas Negroponte, its founder, once put it). Her unique approach to designing social robots informed by best practices from the fields of Artificial Intelligence, Ethology, and the application of animation techniques towards the creation of attractive, living robotic characters, drew me in. From my perspective as an animator, her group’s emphasis on not only the internal, cognitive-affective architecture of the robot but also on the critter’s external appearance and behavior in a social context, were key to convincing me we shared a similar mindset vis-a-vis creating complete living characters.
After reading *Designing Social Robots* and studying the work of her students, I was genuinely inspired and ready to apply myself as an apprentice, a *robo-padawan*.

Armed with over ten years of experience in defining procedural animation systems to create algorithmic processes that brought characters and natural forces to life on the big screen, I decided to take a risk and start along the long road towards animating off the screen, animating robots. On my way through Hollywood, I had the privilege of working with Pixar, Disney, Dreamworks and a multitude of animation studios all over the world, but none of them had active R&D programs in robotics. How might animation techniques, and in particular, procedural animation techniques, map or be ported to robots? I also wondered if robot development pipelines had matured enough to support artistic expression at all levels of the design process.

An animator, it can be said, loves their characters into existence. Beyond the surface, beneath the character's technical rigs made up of inverse-kinematic chains, bones, muscle and movement lies the essence - its style. Upon arrival in the amazing place that is now my research home, I began to notice how each robot in the lab I was going to work in resembled their maker in style. As an artist, I believe that spending that much time with a machine imbues it with something beyond the sum of its mechanical and software parts.

This interest in character development led to some early work in preparing a context for playing with robots. Inspired by Ryan Wistort's squash & stretch robots, I began to ask simple questions about each robotic living character: Where is Tofu (R. Wistort's robot) from?
As Sigurór Örn, one of the PhD researchers in the group once joked “Where do the robots go when the lights go out?” If robosapiens were truly a new species, where was their world? I set about creating an on-screen world for Tofu and his friends. After all, what is a character without a world? Once the world was created, the robot was still on the outside and the world remained trapped in the screen. To integrate the context of play even further I created a mixed reality robot gaming platform and animated a ball (represented as a graphical asset) moving off of the screen and into the space by projecting on to the floor. The resulting simple example resembled an early (Pong-like) game for an integrated robot-video game system. However, the work was clearly not done. I wanted to move the actual, physical robot between the physical world and the screen space or at least give the user that impression. Enthralled by readings on the wonderful imaginary worlds that children create during their private pretend play sessions, I began wondering how one might create an interface that could effectively blur the boundary between fantasy and reality. I started to rephrase my own original question: what if I could animate off the screen to focus on the the blend-point or cross-over point from the screen or imaginary world to physical reality: the interreality portal. Although interest in blending the physical and digital worlds is high on many designers’ minds, one of the unique attributes of my approach is tied to my background as an animator and my belief in the preeminence of motion. Animation is life and life is constantly in motion- all the way down to the subatomic level. In order to truly integrate the physical and digital, this thesis, among other contentions, proposes that the blending of realities must logically include the perception of kinetically continuous phenomena across interreality boundaries.
In the following pages, I document the creation of my take on blended reality as both an auteur and experimental media pipeline designer. I discuss the creation of the Alphabot, the world’s first blended reality character and provide an evaluation of the character, in its unique environment and its impact on young children’s play.
1 Introduction

Imaginative play with blended reality characters explores the creation of a developmentally-appropriate, technologically-mediated experience for young children living through the golden-age of imaginative or make-believe play. It merges elements of technical and artistic expression into a unified play scenario, creating a dialogue between what is and what can be.

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, interchanging bits and atoms, effectively blending fantasy and reality.

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 affordance 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.
This thesis 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 thesis confines itself to exploring the experiential domain of this framework, focusing on the playful interaction between children aged three and a half to seven, and Alphabot, a blended-reality character [Sal03].

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**Blended Reality Framework**
1.2 Thesis Overview

In the following pages, I will describe the concept and design of a blended reality character, and discuss how its 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.

*Ch. 1 Introduction* will begin by informing readers about key definitions, outline this thesis document and enumerate the core contributions of this work.

*Ch. 2 Motivation* will present the need this work seeks to address in the context of the whole child’s physical, cognitive and socio-emotional development. It will also underscore the importance of imaginative play as a fun learning tool for preschool-aged children.

*Ch. 3 Background and Related Work* describes a previous attempt at defining blended reality and advances key differences in our operational definition. It also gives background information on the application of character design techniques for bringing robots to life.

*Ch. 4 Early Design Studies* provides an overview of the ideation process and prototype designs. It details the early development of some of the system’s key concepts and initial versions of working components.
Ch. 5 Blended Reality foundations looks at the fundamental building blocks of the blended reality character's context of play. It follows with a discussion on the critical role the user has in jointly creating the perceived, singular context of interaction.

Ch. 6 Engineering integrated experience will begin by first grounding the engineering work with specific principles and follow with detailed reporting on the experimental media pipeline architecture and its constituent modules.

Ch. 7 Blended Reality Characters focuses on the design and assembly of blended reality characters. This chapter begins with a discussion of the character design principles and gives technical details on the creation of the physical robot and the digital character representation, their inter-dependent control system and the inter-application communication system. The chapter ends with a description of current technical limitations.

Ch. 8 Formative Evaluation will begin by underlining the importance of using a formative evaluation process as a critical component in the design iteration cycle. It follows with a list of observations of children at play with the blended reality character and ends with a brief discussion of an initial test of the robot in a home environment.

Ch. 9 Interaction Design lays out the principles of blended reality environment design and discusses the range of supported options for both visual and audio-based media creators, made available through the system's modular, content architecture.

Ch. 10 Play tests with children describes the formal user study conducted with 34 children. This section will report on the experimental design, the validated evaluation instrument
used and the play test scenario. It reports on the study's findings using a mix of quantitative and qualitative measures.

Ch. 11 Potential as an informal learning tool will reflect on the study's findings proposing the use of the blended reality character system as an effective tool for informal learning.

Ch. 12 Future Work will consider extensions to the system and its potential applications in a broad range of domains.

Ch. 13 Appendix A: A DIT source kit points the reader towards external resources to recreate the experience. Links to computer-aided-manufacturing files and source code for the environment and blended-reality character are provided.

Ch. 14 Appendix B: Spatial Nomenclatures presents two diagrams to help the reader disambiguate spatial terminology used in the play test studies' coded responses.

Ch. 15 Appendix C: Alphabot design origins visually documents the early ideation phase of a connected, educational toy that eventually evolved into Alphabot, the world's first blended reality character.

Ch. 16 Appendix D: Interview excerpts further demonstrates the deep level of engagement of children studied interacting with Alphabot through transcripts from the video interviews.
Ch. 17 Appendix E: Children draw Alphabot presents a visual archive of children's drawings reflecting on their play time with the character.

Ch. 18 References provides a complete list of authors and works cited in the body of this thesis document.

1.3 Contributions

The idea, design and technology of a blended reality play experience is in itself an original concept, and represents a unique synthesis of various media that haven't been extended this way before.

The creation of the system's internal model of a singular, fused reality at this scale, is original. The contributions include techniques related to creating the seamless and persistent blended reality experience from the screen to the real world play space, and back. Furthermore, methods for extending media, typically restricted to being screen-based, into the physical world, are original.

The blended reality character idea of which Alphabot is an instance, presents a new class of continuous character that holds a persistent, visually and kinetically continuous representation across the entire span of Milgram's Virtuality Continuum.

The blended reality authoring pipeline provides a novel means for creative professionals to compose or extend new media properties from a screen-based representation to a mobile robot toy, embedded in a wirelessly connected, augmented play scenario.
The evaluation of the effects of providing a blended reality play experience as substantiated by quantitative and qualitative measures obtained through non-reactive, unobtrusive observation of 34 play tests with children aged three and a half to seven, is a core contribution.

The study found that young children have accepted the idea, persistence and continuity of blended reality characters.

Furthermore, results show that children are more deeply engaged with blended reality characters and are more fully immersed in blended reality play as co-protagonists, in comparison to interactions with strictly screen-based representations.

Based on qualitative and quantitative analysis of drawings and verbal utterances, the study showed 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 shows the potential for the development of an informal learning platform with sustained appeal for young children.

As this thesis lies at the intersection of the humanities and digital technologies, the application domains for this work are potentially broad. In the humanities, this work contributes to informal education practice and sets forth the foundations for distance (language) learning. The technical contributions can be applied to new media design, telepresence, human-robot interaction, the design of new robot gaming platforms for learning and connected toy design for augmented play.
2 Motivation

2.1 The Need

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." [Edw98]

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 [Ung89]. Television is still currently the dominant medium around the world; there are now 250 television sets per thousand inhabitants in the world. In the late 1990s approximately 50 television channels directed at kids were launched with enormous international success [Gig04]. 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 [Nie09]. 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 America have tripled. This year, 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" [Let11]. This thesis 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 ⅞ of American children play computer and video games [Th09]. 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 [Sin06]. 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 [Hir08]. 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.

According to recent reports from the United States Department of Education, only a little over half (57%) of the nation's children are enrolled in preschool [Usd08]. Unfortunately, this number decreases as a function of family income. Nationally, African American children ages three to five have the highest enrollment rates of all racial/ethnic groups. Evidence documenting the alarmingly low preschool enrollment rates of Latino populations is counterbalanced by data showing a high preschool attendance rate of this population in their native country. In a 2011 University of California, Berkeley study, authors cite the Latino preschool enrollment drop (that risks widening achievement gaps) may be due to the rise in joblessness for Latina women and worries among some immigrant families about contact with formal institutions [Ful09]. Ensuring that all children enter elementary school ready to learn is fundamentally important to later academic success. Research shows that children who begin behind tend to stay behind [Van04]. Cultivating a strong foundation and curiosity for learning, both in formal and informal contexts, is essential.
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.

2.2 Supporting imaginative play

Play is a free and voluntary activity with no specific goal. Lev Vygotsky argued that play creates a zone of proximal development in the child [Vyg78]. In play, the child always behaves beyond their average age. Play contains all developmental tendencies in a condensed form and is itself a major source of development. Imaginative play, according to Vygotsky, is the leading educational activity of the preschool years. Imaginative play can make an important contribution to the cognitive and social development of the child [Pia62]. Children engaging in imaginative play are better able to concentrate, develop greater empathic ability, and are better able to consider a subject from different angles [Sin90]. Research studies indicate that high levels of imaginative play in childhood positively relate to creativity in adulthood [Dan80].

Imaginative play develops by age and is influenced by environmental factors. Early manifestations occur around 12 or 13 months of age and by age three imaginative play becomes social. Reaching its peak between five and seven, children delight in the most elaborate forms of social
imaginative play as they start to distinguish between fantasy and reality. Developmentally, during the golden age of imaginative play (five to seven), children begin to recognize that other children can have different thoughts, feelings, motives and perspectives than they themselves have [Sel80]. Similarly, Jean Piaget believed that creativity in children developed around five or six years of age and was due to their newly developed ability to differentiate outer stimuli from internal experience of the stimuli [Pia72].

In the *Handbook on children and the media*, Dorothy and Jerome Singer refer to a *stimulation hypothesis*, citing the work of various researchers advancing the idea that television enriches the store of ideas from which children can draw from when engaged in imaginative play [Sin01]. Overall, none of the studies to date, however, have positively related general television viewing to imaginative play. In a specific case where a children's program was intentionally designed to stimulate imaginative play, experimental evidence did suggest increases in children's imaginative play when limited to specific play contexts and materials related to the program seen [Fri79].

Although studies focused on the impact of general television viewing on children's imaginative play certainly underscore the need for further correlative studies, blended reality play immerses the child in an experience that transcends passive engagement with screen-based, broadcast media. Blended reality play invites the child to physically engage with an embodied character and its tangible manipulative accessories in a more direct, sensorimotor way. This thesis presents a new, interactive medium through which children can engage with a responsive environment designed to support social imaginative play with a blended reality character, and offers an initial evaluation suggesting the impact such technology-mediated experiences can have on children's level of
engagement and the resulting potential the blended reality play experience has as a unique tool for informal learning.

3 Background and Related Work

3.1 The Apple Yard game

In [Hyu06], 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.

Imaginative Play with Blended Reality Characters 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.

### 3.2 Interactive spaces designed for children

In 1996, The Kids Room was built at the MIT Media Lab [Bob99]. The installation consisted of an instrumented kid's room with various props, computer-controlled lighting and sound. Children were guided through a fantasy story, prompted to stay in designated areas of the room during a chapter of the story and asked to use interactive props. The research framework was built around new computer vision action recognition methods.

Blended reality play shares the Kid’s Room inspiration for creating an immersive and responsive environment for children but differs in its approach to participation. Rather than situating the experience within a fixed storyline, the blended reality play environment gives the participating children the autonomy to choose their own level of participation at any point, instead of requiring a "right" action to proceed through the narrative. Furthermore, the blended reality system also presents many opportunities for customization by adult caretakers and teachers so they might affect what’s happening in the space without intruding on what the kids are doing.

In *Funky Forest*, Theodore Watson created a beautiful, immersive play space and invited children to tend to a digital ecosystem [Wat07]. Projected images of water currents on the floor could be 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.
The blended reality play context is inspired by a similar artistic and technical approach towards the production of these types of spaces. We both agree on the importance of 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 expect 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 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-screen.
3.3 Robotic character development

On joining the Personal Robots Group at the MIT Media Lab and being inspired by Dr. Cynthia Breazeal's work in designing sociable robots, along with the research group's tradition of designing robot characters informed by classic animation techniques, I began to reflect on how character development techniques might be applied to robot design [Bre02][Wis10]. I imagined that 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, it would need a back-story, a context or world of its own.

"Where do the robots go when the lights go out?" [Örn11]

proved to be a fanciful yet useful question to propel this research forward. Starting from the assumption that robotic characters, like animated characters, are more than the sum of their constituent parts (e.g. electro-mechanical for robots and drawn lines for animated characters), I realized that providing them with their own world might help people interacting with them move past constantly comparing robots to familiar life forms. Gathering acceptance for this idea 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. I began by designing a home or robot hutch for colleague Ryan Wistort's fluffy squash and stretch robot Miso. The hutch, however, only existed in virtual space. To my surprise, back in 1950, Grey Walter designed a home and recharging station for one of his famed analog Tortoise robots. He interchangeably referred to it as a robot hutch or kennel [Gre50].
4 Early Design Studies

4.1 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, I implemented an interactive, mixed reality (MR) robot gaming platform.

The 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.
The MR robot game was powered by a simulation framework that set the simple game mechanic, tracked the robot and synthesized media in response to the player's input.

The virtual world's high-res background plate used in the game is composed of millions of pre-rendered blades of grass.

This preliminary work set forth the technical underpinnings of modeling a singular, fused reality and documented the design considerations in an ACM publication presented at TEI: Tangible, Embodied, Embedded Interaction 2011 entitled Exploring Mixed Reality Robot Gaming [Rob11].

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.
4.2 The Neverending Drawing Machine

As my personal interest in children's imaginative faculties and their creative expression grew, I became aware of the Reggio Emilia approach to kindergarten. Fascinated with the critical role of the atelierista facilitating collaborative art practice amongst Reggio children, I collaborated with members of the MIT Media Lab's Object Based Media group, Tangible Media group and a talented Harvard Graduate School of Education graduate (Portocarrero, Follmer & Chung) on the design and production of the original prototype of the Neverending Drawing Machine (NEDM). Together we created a scalable, collaborative and networked co-creation system. The system used hybrid analog/digital content-creation techniques and mediated asynchronous communication of image and sound through a networked connection. With the prophesied and sad, near-death of the book publishing industry, we were determined to use a paper book as the principal interface. Our interest focused on the intersection between the traditional paper sketchbook, mark-making tools (e.g. crayons, makers), everyday objects (often with personal meaning) and digital tools. The results of our initial exploration were published in ACM Ubicomp 2010's First International Paper Computing workshop [Por10].
The fascinating unpredictability of the Neverending Drawing Machine (NEDM) co-creation platform made looking at the results of the Reggio-inspired auto-documenting feature very rewarding. Children (of all ages) were co-creating evolving story worlds, using the tables as a means for connecting with each other and sharing their personal experiences.

In contrast to narrow definitions of early literacy, the Reggio teachers believe that even though the preschool child cannot yet write, the act of drawing is a productive form of expressive communication, one that can easily be shared across linguistic and cultural boundaries.

In initial designs of the system that would later become the ground upon which the blended reality play experience was built, I experimented with incorporating an altered version of the NEDM that scaled up one of the tables or creation stations's output to a much larger space children could freely move around in.
5 Blended Reality foundations

Careful integration of physical and digital space is required along with implied viewer acceptance, in order to synthesize a blended reality environment.

5.1 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 [Pha11]. In addition, custom made wooden platforms attached to the truss hold four audio speakers. 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 image. Four short-throw projectors hung from the truss system and oriented downwards towards the white floor mats project the ground image.
digital environment with back wall and stitched floor projections
5.2 The digital space

The digital world is rendered in real-time on two dedicated graphics computers. One of the computers is allocated to rendering the main back wall screen while the other renders four live images projected on to the floor. The unavoidable differing mounting angles of the top four, truss-mounted projectors, result in individually skewed projections on the floor. To correct this, a calibration routine and image stitching process is run. Without this critical step, the projected images would overlap, unable to deliver a seamless final image to the floor. The process begins by projecting a dot pattern from each projector and photographing the scene using a digital SLR camera. The resulting images are processed through custom software that calculates a homography or projective linear transformation and outputs eight files: four two-dimensional UV texture maps that specify the individual image warps necessary, as well as four images containing alpha maps denoting overlapping areas [Ras98]. All of these images are loaded into a real-time process running on a graphics processing unit (GPU), warping incoming image streams and alpha blending the juxtaposed projections, producing a cohesive final image. This process relies on ensuring that the four pre-processed projections overlap with each other by at least twenty percent. Essentially, some of the projection area is lost but the resulting large-scale floor image makes it worthwhile.
interreality portal & robot hutch

Source: After Milgram et al. (1994)
5.3 The blended context for play

Once media has been produced and tailored to adorn both the main back wall screen and the floor, a mixed-reality interaction environment is created. Paul Milgram and Fumio Kishino defined Mixed Reality (MR) as “anywhere between the extrema of the virtuality continuum” [Mil94]. 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 which is typically restricted to being screen-based, into the physical world where it can be physically interacted with in a naturally intuitive and tangible way. The 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. Furthermore, the extensible nature of the digital subspace in the blended reality play context provides a mechanism for people of all ages to play and communicate with each other beyond language, across physical distance, and across cultural boundaries.
5.4 Co-Animation

Natural responses do not require complex, intellectual processes on the part of the viewer. Often, what seems true is more important than what is true. The artist Robert Irwin declared that perception itself, independent of any object, was the true art act [Wes82]. Social and natural responses come from people, not from media themselves. In order for a blended reality to be intuitively accepted, the unique environment and the blended reality character must be co-animated or jointly animated, whether conscious of this suspension of disbelief or unconsciously by the viewer. People automatically assume the primacy of reality because throughout human evolution there was no reason to doubt it. Studies by Byron Reeves and Clifford Nass, borrowing methods from sociology, have shown that when perceptions are considered, it doesn’t matter whether a computer can really have a personality or not. People perceive that it can and respond socially on the basis of perception alone. These responses could be unfairly labeled as irrational but they are merely human and part of any communication experience [Ree96]. Relating to a blended reality character in its native environment requires the viewer to engage in an act of social imaginative play regardless of their age. Moving past the idea of a machine or robot and directly engaging with the character, as simple as it may be, connects the viewer to its most prominent formal feature: it’s world or context of blended reality play. This intimate connection with the character’s fantasy world has the potential to lower expectations of realistic behavior, making comparisons with the real and familiar world, at best, unsuitable. In this manner, the resulting participation in social imaginative play creates the opportunity for deepening engagement with the character and thus profoundly affecting the quality of the interaction itself.
5.5 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 (e.g. using bezier curve interpolation) 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 Alphabot’s translate Z parameter is shown above 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 Alphabot 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 [Gin07].
6 Engineering integrated experience

This section sets forth the technical underpinnings of the current system. Providing an integrated experience requires the thoughtful assembly of an experimental media pipeline able to deliver a broad range of cross-modal experiences.

6.1 Engineering design principles

This 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 robotic platform providing motility for the Alphabot is controlled by an on-board, embedded Arduino program running on the micro-controller connected wirelessly to the robot control software [Ard11]. Engineered in Java, the robot control software runs on a Mac OS laptop that also operates the system’s sound software module. Sound synthesis and processing is done in Ableton LIVE and Max/MSP [Abl11][Cyc11]. Open Sound Control (OSC) connects the robot control module to the main system control and real-time animation module, running Touch on a 64-bit Windows OS graphics supercomputer [Der11]. The Phasespace motion capture system provides a Linux server streaming robot localization data over the network, to the main Touch control environment via a Python to OSC translation module.
6.3 Environment control software

The system's synthesized graphics, event choreography, signal processing flow, and inter-application communication's hub, run in a constantly evolving and experimental Touch project file. The environment control software works on providing 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. The control software can be re-programmed on the fly without need for recompiling, thus making it an ideal, live rapid prototyping environment.
6.4 Graphics synthesis

The graphics system renders a total of 7 million pixels (7,077,888) at interactive rates on two computers serving nine screens. The system makes extensive use of Graphics Processing Unit (GPU) accelerated methods to synthesize the resulting experience. The current system relies on NVIDIA Quadro-class GPUs to render and output imagery to seven projectors and two control system operator (sysop) computer monitors. The graphics computers are dedicated to rendering for the three paneled screens that define the back wall of the space as well as stitching a large floor projection from four XGA (1024 x 768) video outputs. The system uses Matrox Dual and TripleHead2Go multi-monitor adaptors to produce a total of ten VGA outputs. The following figures illustrate the current graphics output capabilities.

SYSOP view:
1024 x 768 = 786,432 pixels

WALL screens:
2304 x 1024 = 2,359,296 pixels

WALL RENDER NODE TOTAL: 4096 x 768 = 3,145,728 pixels

SYSOP view:
1024 x 768 = 786,432 pixels

FLOOR screens:
2048 x 1536 = 3,145,728 pixels

FLOOR RENDER NODE TOTAL: 4096 x 768 = 3,932,160 pixels
The main rendered view is transformed, cropped and treated by an output subsystem as part of the stitching process. To provide a seamlessly integrated visual experience between projected image edges, the module alpha blends each projection output with overlapping and neighboring projections. Moreover, the imagery is warped in real-time to fit and work around the available geometry of screen configurations. This computationally expensive process, in addition to rendering the world itself and providing seven unique 1024x768 views on it, consumes most of the graphics resources.

The back wall render node computes a 2304 x 1024 image with an aspect ratio of 2.25:1.
6.5 Sound synthesis

The audio system is comprised of two main components (system & user driven) running in Ableton Live, chosen for its ability to seamlessly synchronize all layered material to a master tempo reference [Abl11]. In addition, Cyling74's Max/MSP and Max4Live are used to collect and condition incoming controller signals [Cyc11]. The inter-application communication protocol used is Open Sound Control (OSC) [Wri11].

Controller signals representing the absolute location of the robot player on the game floor board or the relative distance of the robot player to a given human or game element, are routed in one of two possible ways: triggering an audio clip from a matrix of related options or modulating a synthesis parameter/changing a level on a virtual mixer.

In addition to processing incoming signals for the audio synthesis and arrangement process, the built-in sequence in Live is used to sequence the robot’s on-board LED to blink in time with the musical elements of the game if desired.

The sound is distributed in space through four speakers at the corners of the play space connected to a multi-channel digital audio card controlled by Live through Max, interpreting control commands streaming in over the network from the main environment control software module.
6.6 3D motion capture

The system uses the PhaseSpace IMPULSE motion capture system consisting of 8 high-sensitivity 12.6 megapixel cameras positioned overhead surrounding a 19 x 9 x 19 foot tracking volume.

The robot tracked is outfitted with 5 LED markers strategically placed on each lateral face of the Alphabot as well as on its top. Each marker emits a unique light pattern in the infrared frequency range. With a sample rate of 240 Hz and a latency of less than 10ms, the PhaseSpace IMPULSE system is a fast and accurate way of capturing even the most subtle movements. The server receives data from the cameras, tracks Alphabot’s active LED markers and groups them to represent a single rigid-body. Once this rigid body is computed by the server, x,y,z co-ordinates and a theta angle indicating robot orientation are made available for reception by a client.

Using the custom client-building API and provided Python modules, a simple client was created to poll the PhaseSpace owl server for live motion capture data and conversion to an OSC stream for interpretation by Touch: the visual programming environment used to integrate and choreograph all modules.
6.7 Inter-application glue

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, provide native support for OSC.

In an effort to future proof the system and integrate it into a wider robot lab practice a C++ program allows for integration with our research group’s inter-robot-communication-protocol (IRCP), thus paving the way for collaborative multi-robot projects.
7 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.

The above photo shows an example of a break in character continuity. Alphabot is seen doubled both in the physical and virtual spaces, breaking the illusion of the individual character.

Creators must get to know the blended reality character before it can be fully developed. 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 [Ree96]. 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 its dual representation in blended reality. A strong, consistent personality embodied in a simple form helps reduce
complexity and deliver on expectations. When people know what to expect they can process media with a greater sense of accomplishment and enjoyment. 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 the first 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.

7.1 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) [Loc23]. 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 [Bro02][Natl11].

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.

Above: Alphabot's input/output mappings
Below: A landscape of 3D alphabet blocks
7.2 Physical Alphabot

Robot overview
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.
Mechanical design

Alphabot is constructed out of baltic birch plywood which has been laser cut and assembled. Twenty-four metal elbow bracket fasteners are used to secure the panels together. A thin, light-permeable sheet of velcro is adhered to an eighth of an inch sheet of acrylic framing the front face of the robot. A custom bracket internally mounted behind the robot's front face holds an RFID reader and an RGB LED. A small, rear maintenance port grants access to the robot's main power switch.

Alphabot uses a differential drive mechanism for mobility. Two 24V DC gear-head motors are used to move the robot. The motors are fastened to the bottom plate of the robot using a custom Delrin bracket. Each motor drives the robot using a three inch foam wheel. Two casters, one on the anterior and the other on the posterior of the robot base are mounted using custom wooden brackets. A two-inch high, raised wooden platform mounted to the bottom plate of the robot provides just enough room for electronics, communication and power. Batteries are stored in a central position keeping the robot stable and with a low rotational inertia.
Fabrication

The Alphabot was built in the MIT Media Lab’s fabrication facility (Fab Lab), thanks to the environment created by the Center for Bits and Atoms and the wonderful shop mentors that maintain this rapid prototyping facility on the ground floor of our research lab. The robot’s main panels were constructed out of Baltic Birch wood, sourced from Boulter Plywood in Somerville, MA. I output two-dimensional, orthographic projections of each component piece in Alphabot’s three-dimensional, Solidworks assembly, and transferred the resulting DXF geometry files to a Fab Lab computer connected to a Universal Laser Cutter, a machine that cuts various materials with a focused beam of light. In order to cut through 30” x 20” flat 1/4” wood panels I experimented with various settings until I found the following amounts for power, speed and pulses-per-inch to be optimal for both cutting and rasterizing images (the MIT and HGSE logos).

<table>
<thead>
<tr>
<th>Baltic Birch</th>
<th>Power</th>
<th>Speed</th>
<th>PPI</th>
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<tbody>
<tr>
<td>1/4” cut</td>
<td>100%</td>
<td>0.85%</td>
<td>1000</td>
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<tr>
<td>1/4” raster</td>
<td>15%</td>
<td>60%</td>
<td>500</td>
</tr>
</tbody>
</table>

As these settings were not yet recorded in the Fab Lab’s material settings, I recorded them for other fabricators’ future use. Alphabot’s custom motor housing was made in a similar fashion as above but using Delrin, an easy material to machine. I ran two back-to-back passes with the following settings:

<table>
<thead>
<tr>
<th>Delrin</th>
<th>Power</th>
<th>Speed</th>
<th>PPI</th>
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<tbody>
<tr>
<td>1/4” cut</td>
<td>100%</td>
<td>1.2%</td>
<td>1000</td>
</tr>
</tbody>
</table>
As I wanted the Alphabot’s face to be translucent to allow the RGB LED light to shine through the front face, I chose a 1/8” thin, clear Acrylic stock and cut it with the following settings:

<table>
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<tr>
<th></th>
<th>Power</th>
<th>Speed</th>
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<tbody>
<tr>
<td>1/8” cut</td>
<td>100%</td>
<td>4.2%</td>
<td>1000</td>
</tr>
</tbody>
</table>

Overall, ninety percent of the Alphabot is made from wood, a material I really enjoyed working with, and reminiscent of the classic preschool wooden letter blocks the design was inspired by. The wooden symbols used in conjunction with Alphabot were also manufactured in a similar way. Initially, symbols were laser cut and then RFID buttons were affixed to the back of each symbol with glue. In later symbol production runs, a process was developed whereby the symbol was cut out of a material half the desired final thickness and then laminated together with an RFID tag embedded in one of the layers. By carving precise 16mm holes out of one of the layers, the RFID button would remain coplanar with the symbol’s back face.

By design, the Alphabot’s production process can be replicated at any of over fifty Fab Labs in the international network of mirror facilities [Fab11]. This fact presents a wonderful opportunity for making the Alphabot at international Fab Labs, possibly in collaboration with local crafts people using local materials.

**Robot assembly**

Putting the robot together is easily accomplished by fastening the sides together with short, ninety degree metal brackets. The face of the robot frames a thin acrylic panel covered in white, adhesive velcro.
Aiphabot's electronic subsystem is comprised of easily accessible and inexpensive off-the-shelf parts. Where possible, open-source hardware was used.

**Electrical design**

The Alphabot's interior reveals a two-tiered stack of electronic components, wiring, batteries and an Arduino stack at its core. The Arduino, an affordable, accessible and standard open hardware platform hosts an ATMEL ATmega328P 8-bit AVR RISC-based micro-controller with a serial interface, a 6-channel 10-bit analog to digital converter and operates between 2.7 and 5.5 volts [Mel07]. The power is supplied directly from two centrally located batteries that feed both the micro-controller and the motors connected via an L298 H-bridge circuit mounted to the Ardumoto shield [Ard11]. In turn the H-bridge circuit is controlled through the Arduino's interpreted serial commands. These commands, through the H-bridge chip, adjust the rate and direction of each motor on the robot. The rotating motor shafts are coupled to three inch foam wheels, enabling the robot's locomotion. The computer running the robot control software continuously issues motor commands over a bi-directional, wireless 2.4Ghz data link used to send serial data. Control electronics on the robot convert the serial data in to the robot's output.
A bright Blink-M MaxM RGB LED is powered directly off of the Arduino board, and wired into four analog pins to provide complete and direct control over the color of the light that Alphabot animates as needed via commands sent on a I²C bus [Bli11] [Phi00]. The BlinkM MaxM unit contains three large 10mm light-emitting diodes (LEDs) combining the forces of 15 individual LED cores to create an intensely bright light. This is desirable as the unit is internally mounted behind the Alphabot’s semi-translucent face and needs to permeate through a thin sheet of white velcro to reach the exterior.

An ID-20 RFID reader wired to the Alphabot’s Arduino microcontroller reads RFID tags embedded in Alphabot’s tangible symbol tokens and communicates the identified symbols to the micro-controller. For further details please see Section 7.3.

The robot’s detachable on-board batteries supply the robot with a tested four and a half hours of continuous running power. A standard battery recharger replenishes the batteries in about one hour. The Alphabot’s electrical sub-system is wired to a master on/off switch conveniently positioned and accessible from an opening in the rear panel.

**Embedded programming**

The embedded program that runs on the robot’s ATMEGA328P 8-bit AVR RISC-based micro-controller is written in the Arduino Integrated Development Environment and automatically compiled with Avrdude [Dea11]. The robot’s embedded program can be easily updated while tethered to a computer via universal serial bus (USB).
The Arduino code performs multiple tasks. The first is parsing incoming and outgoing UART data packets sent through the wireless 2.4Ghz data link from the robot control computer. The Xbee radio transceiver uses the micro-controller’s designated serial RX and TX pins. Target wheel velocities are sent to the robot and used to control the speed of the motors. Variable control over the speed and direction of the motor is achieved by pulse-width modulation (PWM) and an H-bridge circuit on the Ardumoto motor shield.

Similarly, the embedded program receives commands wirelessly from the robot control computer and sets the color and intensity of the robot’s on-board Blink-M MaxM RGB LED. The manufacturer of this device provides a high-level, embedded software function library to easily control the three surface-mounted LEDs. The robot’s embedded program calls various color-setting functions in the BlinkM library and the output is sent to the LED array over an I2C bus. In addition to setting colors from the robot control computer, the current implementation reads an embedded lookup table in the micro-controller’s memory with hard-coded color mappings for tangible symbols detected on the robot’s front face. This flexible architecture allows Alphabot’s LEDs to give direct feedback to the child as they affix a wooden symbol to its face, but also allows the larger media system to control the robot’s lighting system in case the system’s media content designer wants to synchronize and color-match the robot’s light output to on-screen visual events.

As the communication hardware between the robot and the robot control computer uses the available micro-controller hardware serial receive and transmit ports, a software serial library works around this limitation by repurposing the digital input/output pins on the micro-controller, providing “soft” serial support for the RFID reader [Har11].
Implementing this library to establish communication with the RFID reader, the embedded code proceeds to compare detected RFID tags to a lookup table containing value pairs that map to Alphabot’s available wooden symbols. A data type conversion takes place and the resulting serial command string is sent directly to the LEDs and to the robot control computer via the aforementioned wireless uplink. Adding new symbols to Alphabot’s repertoire simply requires updating the lookup table and re-uploading it into the micro-controller’s memory.

For further details on the symbol recognition system please see section 7.3

Communication with system
Alphabot maintains a constant bi-directional communication link with robot control software running on a dedicated computer, hooked into the private network reserved for the blended reality play experience. An Xbee Explorer integrated circuit conditions power and hosts an FTDI FT232RL chip that takes care of the USB to serial conversion before passing signals from the robot control computer to the radio.

The 2.4 Ghz XBee Series 2 radios found on both ends of the communication pipeline use a 1mW chip antenna. These reliable and high-performance radios were chosen due to their availability and excellent co-existence with wireless local area

66
networks, Bluetooth and other 2.4 Ghz devices. In a noisy environment, we were able to get a reliable 53 feet from the radio connected to the computer, to the robot, across a non line-of-sight path partially obstructed by walls and colleague David Cranor's experimental electronics. The blended reality play space measures 12 by 13 feet and the robot's typical use constrains it to inside this area, making the radios' effective range more than suitable for our purposes.

In essence, these radios enable wireless communication between anything with a serial port (e.g. micro-controller on a robot, computer). They take the IEEE standard 802.15.4 stack and wrap it into a simple to use serial command set. In addition to their easy serial interface, the radios consume less than 50mA when working hard, which in our case is all the time as we are constantly streaming motor commands from the control computer to the robot.

On the robot, the Xbee radio connects to a Sparkfun XBee shield that mates and draws power directly from the micro-controller. The Xbee radios are individually identified and paired in a point-to-point network using XCTU configuration software which at the time of this writing, unfortunately, only runs on 32-bit Windows. A command-line interface allows direct configuration in case it becomes necessary to bypass using the convenient XCTU software.

The robot does not communicate directly with the interreality portal/hutch. Rather, the main blended reality environment control computer choreographs the opening and closing of the hutch doors in concert with the appearance and disappearance of the virtual or screen-based representation of Alphabot.
7.3 Alphabot symbol token accessories

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 [Gho92]. 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 [Fis04].

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 for 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.
7.4 Digital Alphabot

3D geometry
Alphabot's virtual representation is designed to be as consistent as possible with the robot version of the character. 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 taking place on the main computer controlling the blended reality play experience, keeping Alphabot geometrically simple creates opportunities for future migration of the blended reality character onto mobile platforms and other devices lacking 3D graphics prowess.

The 3D digital representation of Alphabot is created using Touch Designer's Box SOP (surface operator). Rather than load in a static geometry file from disk, the parametric definition allows for dynamic surface geometry changes. As the robot's shape evolves over future iterations so will the procedurally-generated 3D representation.
Surface appearance

Digital Alphabot's surface appearance leverages a common environment mapping technique known as cube mapping optimized for real-time rendering [Gre86]. A single texture map per symbol is prepared in Adobe Photoshop. The image stores six square textures unfolded into six regions. As the bottom of the Alphabot is never seen we leave it blank. UV texture coordinates applied to the box geometry, aid in aligning the projected cube image map on to the constituent faces. 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 straightforward, 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 [Ros04].

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.

Adding a new symbol to the current play set is accomplished by first, taking a picture of the physical, wooden symbol, compositing it over the blank Alphabot cube map template in Photoshop and adding the result as a new input into the switching network for the cube map sent to the real-time surface shader. Finally, the symbol ID lookup table embedded in the robot’s micro-controller is updated to reflect the new option and a suitable color-mapping for the on-board LEDs is created.

Since Alphabot’s geometry doesn’t have any curvature specular highlight calculations can be disabled further optimizing the real-time rendering pipeline.
7.5 Animating Blended Reality Characters

Blended Reality Animation Pipeline Overview
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.

Alphabot can fluidly move across the entire span of the Virtuality Continuum

Traditional keyframed Input
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. Animators populating the animation clip libraries are asked to help smooth the blending process by delivering segmented assets with established start, end and loop points. In the case that the animation clips supplied do not conform to these standards a suite of animation clip trimming and time-warping tools are available.
Touch’s CHOPs or channel operators are used to process the blended reality play system’s motion data, synthesize motion and condition and route live signals. In addition, the system makes extensive use of CHOPs for control logic and managing the overall hybrid animation pipeline. A CHOP can contain multiple channels of time-series data and operate on a whole animation clip or a user-set “time-slice.” The latter technique is used to maintain interactive rates and process hundreds of channels without impacting the frame rate.

*Internal view of Alphabot’s hybrid animation control system*

**Procedural motion synthesis**

CHOPs non-destructive nature make them the ideal rapid-motion-prototyping tools allowing safe exploration and live pipeline reprogramming. Seemingly taking inspiration from analog modular sound synthesizers, CHOPs are used to procedurally synthesize motion for Alphabot and other elements of the 3D world. For example, a sine wave oscillator is used to generate Alphabot’s on-screen jumping behavior. The oscillator is tuned per taste while the system operator observes real-time updates in the blended reality play space. The current Alphabot jump is controlled by a dampened low-frequency sine wave, remapped and added to the character’s current Y or vertical coordinate. Alphabot’s jumping pattern
can change every time, if desired. Procedural motion systems like the one designed for the blended reality play space allow designers to quickly explore a large parameter space until pleasing and suitable results are found. In essence, the pipeline is never frozen and is constantly evolving, in the same way a patching session of a large, modular synthesizer can go on endlessly. The internal architecture of blended reality play is, at its core, an imaginative playground.

The Alphabot’s digital world contains an oversized bee that appears to buzz on to the screen every once in a while but always in a different way. This effect is achieved by generating an endless stream of Brownian noise, setting the noise generator’s integral parameter to 2 and running it through a Gaussian filter. The end result is time-sliced, scaled into a new range and then sent to the x,y,z coordinates of the critter which appears to fly continuously around, pseudo-randomly adjusting its acceleration every frame - like a bee.

Performance animation
For Alphabot’s basic hill-climbing animation displayed during the play tests, individual, animator-sourced clips are loaded into a table referenced by a clip blending subsystem. Scripts implemented in Touch Designer Pro’s visual programming language selectively replace the blend from and to parameters based on system operator designed logic and incoming button presses from a connected, wireless joystick. Using the designed pipeline, as the animation clips play back, the procedurally-generated jump and spin motions can be triggered and added to the digital Alphabot’s live motion. This approach to mixing animation techniques (traditional, procedural and performative) helps compartmentalize and therefore manage complex motion in a fluid and enjoyable manner. Among other functions, the joystick input signal processing network routes button-presses to user-event dependent script execution mitigating the processing
overhead of the overall system. Additionally, input from the joystick's two analog sticks is sent to a robot safety checker that clamps minimum and maximum values.

The resulting signals are transmitted to the robot control computer using the OSC inter-application protocol. The running Java program implements an additional robot safety checker and issues wireless serial commands to the robot controlling its motors. The standard differential drive robot is easily tele-operated from the joystick, but routing it first through the blended reality environment control system makes it easy to coordinate the blended reality character's on-screen representation with the real robot. Finally, a button on the joystick also triggers the hutch doors on the interreality portal to open and allow for the transmediation of the character on and off the screen. Since the main blended reality environment computer models a singular, blended reality context of play and both the digital and robot forms of the Alphabot character are controlled from within the environment the resulting perceived continuity of the character across interreality boundaries is ensured.
7.6 Limits of current system

The inexpensive hall-effect’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.

Three physical changes to the robot could greatly add to its overall design: first, the activation of its top face as the main focus of interaction for the child; secondly, the addition of a simple up and down degree of freedom to give the physical robot added expressivity and finally, the ability to independently adjust torque on the robot’s wheels as they slip on uneven terrain if we want to further enable its motility, especially in a home environment.
8 Formative Evaluation

Formative evaluation helps the designer of a product or experience, during the early development stages, to increase the likelihood that the final product will achieve its stated goals [Fla90]. Evaluation in this definition, means the systematic collection of information for the purpose of informing decisions to design and improve the product. The term formative indicates that information is collected during the formation of the product so as to uncover practical design considerations and iterate on the design, thus improving the final outcome. The following section outlines some of the observations on the perceived continuity of the blended reality character and generalized insights pulled from informal observation of children interacting with Alphabot.

8.1 Observations

Over the course of several months we had the privilege of hosting several groups of children in our lab and were delighted to observe interactions between groups of children and the blended reality character, as well as with the environment itself.

Children were fascinated with Alphabot’s blended reality transmediation capabilities. First and foremost, we observed an immediate fascination with moving the Alphabot on and off the screen. The robot would emerge from its hutch, into physical space and within moments the children interacting with it wanted it to go back into its digital world on-screen. Similarly, the character would be on-screen for only a few brief moments before it was summoned to come out and play. This pattern repeated itself throughout the entire play session.
Children spoke naturally, addressing the character by name (While up on its virtual hill) "Alphabot, come down here"
They also addressed the Alphabot by the same name while the character was co-located with them in physical space by issuing verbal directives:

"Alphabot, go in the grass"
"Alphabot, follow the note” (symbol)
"Alphabot, turn around"

Children's eye gaze behavior was observed tracking the character as it moved from physical space to its digital world on-screen, even among children who peeked behind the portal doors to see what was happening or helped by making sure the doors closed after Alphabot.

We also observed a child who was determined to enter the digital space himself and managed to crawl inside the hutch. On another occasion, a young boy put his toy car in the hutch possibly expecting it to show up on-screen.

On yet another occasion we observed a child engaged in mimicry of the character's on-screen behavior. When the Alphabot jumped on-screen the child would jump. If the Alphabot spun around on-screen, the child would also spin around.

In addition, we carefully observed the physical interaction between the robot and the child. Children did not appear to be intimidated or threatened by the robot. On the contrary, children often pushed the robot around with both hands, forcefully bringing it to the entrance of the hutch with the expectation that it would go in and through to the other side. In-line with our design philosophy of leaving white space in the robot to create room for unanticipated uses, we observed children affixing symbols to the robot's inactive top face.
Due to the relative size of the robot to a young child, it became abundantly clear that the top face was the easiest one to reach and should be activated in future designs.

8.2 Alphabot in the home

In addition to play tests of the blended reality character in its environment, I brought Alphabot home one evening to try to initiate some thinking about Alphabot in a residential scenario. As the robot fit into a large backpack, transporting it home by bicycle was effortless. Once home, rolling around on hardwood floors while the occupants went about their usual activities was easy as the robot was tele-operated. Immediate challenges that surfaced were related to both physical and social factors. Alphabot could not make it over the threshold dividing hardwood and carpeted areas of the house due to its low-profile design. The low friction wheels chosen for rolling around in the lab space did not provide enough grip and the wheels began to slip, spinning in place. Additionally, when the home occupants sat down to watch a movie, one of the desired roles for the Alphabot was to take on the task of going on round trips to the refrigerator and acting like a personal assistant rather than a preschool toy. This indicated that a multi-use and multi-generational design for the robot might be desirable to allow all of the inhabitants of the home to benefit from and maintain positive relationships with Alphabot if we were ever to port the blended reality play experience to the home environment. What might the Alphabot do when the kids go to sleep?
9 Interaction Design

The interaction and overall pipeline design of blended reality are implemented in TouchDesigner, the most complete authoring tool for building interactive 3D experiences. This tool has an extremely rich geometry, motion, rendering and compositing feature set designed by a talented team of Academy-award winning computer graphics veterans. The visual programming environment provides a base upon which high-level graphics and signal processing methods can be authored and shared. This tool was chosen due to its ability to work well with other applications and its proven track-record in delivering experiences on this scale. Seen here (below) is the interaction designer's workstation consisting of two graphics supercomputers with line-of-sight visibility to the environment being programmed. It should be noted that the final design of blended reality experiences must happen from within the space. Animations, sounds and assets may seem to work in the virtual world but porting them to blended reality requires a fine mixture of precise calculations and signal massaging. The resulting work is truly a mixture of media arts and sciences. In some cases the technically correct solution is not always the one that communicates the intended message or feeling. Therefore, design considerations on both the micro-level of each participating asset and the macro-level of the
resulting complete experience need to be carefully balanced to achieve fluidity and grace.

Due to its procedural architectural design, blended reality presents participating creatives with an agile and flexible environment. Very few of the media assets used are locked in to the programming structure in a way that would make changes difficult or time-consuming. Like object-oriented programming, various processes and sub-processes are defined, abstracted, referenced and instanced throughout the program, making it easy to substitute assets, re-target logic networks and script programmatic control. In cases where non-procedural, "dead" media (e.g. a video clip) are used, efforts are taken to wrap them in procedural methods for future use and adaptation.

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. Based on research into the amount of space needed by active, healthy children, we chose to design the experience around a maximum of three child users. During a typical play session, children may change roles and adults might be invited to moderate or help model the use of an interface. Adult tele-operation of the robot, opening/closing of the hutch doors and triggering the character's virtual ascent up a hill in the digital world, enables a careful human-powered choreography and ensures visual and kinetic continuity. The unpredictability of children interacting with Alphabot generates many surprise effects as they grasp, move and accidentally damage the robot. A sense of humor and an understanding that making a
robust, child-proof system is difficult helps move the design forward following minor setbacks. The learning experiences gained through the use of formative evaluation were of critical importance and helped reshape the experience.

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. Children do not need much explanation about what is going on, they seem to run right into the environment and start to play - a good sign.

9.2 Content Modules

Visual media
The visual components of the system include: 3D animations, 2D animations, 2D images, movie clips, 3D geometry, realtime shaders and the design of the overall, interactive lighting system which changes based on the world’s time of day.

Careful attention was paid at the authoring level by professional content producers, providing media for the system to ensure their contributions remained in cannon with the overall aesthetic design. The rendering style and visual appearance of the world was designed to appear simple and sparse. By foregoing the use of a photorealistic style we authored 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. Had we chosen to use a photorealistic style, children’s submissions (e.g. a child-drawn flower) might have been viewed in contrast with backgrounds produced by professional media designers and not integrate properly. Even worse, their efforts would appear to be treated as second-class citizens. Efforts were made to use chalk and watercolor textures and create an inclusive world.
As in traditional animation practice, everything starts with a story. The design of the world went through various white board iterations (seen above) 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 enhanced the dramatic effect of having Alphabot come out and play. Although Alphabot could come down and play from any hill we chose to keep the character in one location for consistency and allow the other hills to be mostly unoccupied. Story authors know the importance of leaving room in a character or a story for the reader to fill in the blanks with their imagination. Leaving hills open to the possibility of a journey to a distant land or the visit from a far away adventurer was a conscious decision in the hopes that it might further spark their imaginative play activities.

F. Faradi draws the French cafe scene triggered by the mustache.
Sound design
Moviemakers agree that a picture tells only half the story. Mood can be evoked through sound. Ambient sound plays a large role in cuing people in an immersive environment. For this reason we chose to use a layered approach in designing the soundscape. Please see details in Section 6.5

Creating a flexible, reactive soundscape made tangible by the manipulation of symbolic tokens placed on the robot, requires a coordination of both the underlying architecture and the careful arrangement of sound motifs composed to work together in layers or sequence. Designing sounds for blended reality must take into account the environment’s unique attributes. Spatialization cues as well as attention-dependent, location-based triggering are set to create a desired effect. For example, an ambient sound could be animated to make itself heard coming from the left rear speaker and slowly panning through the space, indicating movement. In the same vein, relationships between children and the robot can be sonified based on distance from each other or interaction patterns. Most importantly, sounds in the system can play on top of each other regardless of differing source tempos, avoiding rhythmic cacophony. Sounds can only enter into the soundscape at the beginning of a new rhythmic measure and are time-stretched in real-time, resulting in the perceived match in tempo. This formal characteristic of the medium allows for long-distance sound collaboration - an as of yet untapped potential. In debug mode (seen here) the yellow and blue dots indicate sound hot zones triggered by the robot.
10 Play tests with children

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.

10.1 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.

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

We play tested 34 children ranging from as young as 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 general age bracket [Sin01].

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.

Size: 34  
Females: 12  
Males: 22  

Age range: 3.5 to 7  
Avg. age: 4.88  
Avg. age (F): 4.77  
Avg. age (M): 4.95
10.3 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. If parents arrived with two children to be tested, the children were separated and the one not being tested was kept busy with another age-appropriate activity away from the testing area. Care was taken to ensure every child was experiencing the play test area for the first time and that both the parent and child knew that participation in the play test was voluntary and that they could stop the test at any time.

10.4 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. The following table indicates the effect of placing each of the six symbols on the Alphabot’s face. Five of the actions would take place only once the Alphabot had gone through the hutch and climbed its hill in digital space. One of the actions took place immediately: placing the mustache on the Alphabot would change the environment to a french cafe scene.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Visual</th>
<th>Audio</th>
</tr>
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<tbody>
<tr>
<td>🇯🇵</td>
<td>Japanese portal is displayed and introduces a new friend: an Alphabot from Japan</td>
<td>triggers the sound of a loud gong being struck</td>
</tr>
<tr>
<td>🎵</td>
<td>triggers a happy-sounding short sound motif</td>
<td></td>
</tr>
<tr>
<td>🎵</td>
<td>triggers the playback of the Alphabot theme song (composed by B. Illgen)</td>
<td></td>
</tr>
<tr>
<td>🎵</td>
<td>triggers the sound of an ascending chime glissando</td>
<td></td>
</tr>
<tr>
<td>🎵</td>
<td>animation of Japanese counting numbers 1-3 displayed in sync with audio</td>
<td></td>
</tr>
<tr>
<td>🎵</td>
<td>Japanese counting sequence “ichi, ni, san” spoken by disembodied Japanese female (system) voice</td>
<td></td>
</tr>
<tr>
<td>🎵</td>
<td>background cafe sounds are heard layered beneath a French accordion song which lasts 20 seconds and begins after ambience is established</td>
<td></td>
</tr>
</tbody>
</table>

Symbol mappings used during play tests matched across both conditions
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.

10.5 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 to make use of age-appropriate language. We started by asking each child in both conditions the following questions:

*How much fun did you have?*
*How much fun do you think Alphabot had?*

To help children understand what was expected of them, response options were presented to them in picture form:

![Smiley Face Assessment Scale (SFAS)](image)

The Smiley Face Assessment Scale (SFAS) is one of a number of attitude assessment scales used primarily to measure the affective domain of children. The scale is a Likert-type self-report assessment instrument with a pictorial response system.
A five-point SFAS was adopted and used for this study [Hen87].

10.6 Validated measures

Historically, the development of attitude scales was due primarily to the work of Thurstone, Likert and Guttman [Aik76]. The Likert scaled developed by R. Likert is a method of obtaining information pertinent to affective variables. Hopkins and Stanley stated that pictorial response scales are sometimes more effective for assessing attitudes, especially for children [Hop81]. Henderson, Morris, and Fritz noted that the major problems hindering the assessment of children’s attitudes are that they have short attention spans, an inability to understand questions, and difficulty keeping their places [Hen87]. For our study, we found that the smiley face scale was a useful 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.

The interview continued with three questions created to discern the child’s conception of the blended reality character. The first question:

**How many alphabots were there?**

was used to ascertain the continuity of the character. We wanted to know if the child saw the physical robot and computer graphics character as one and the same - if the character was perceived to be continuous across the physical and digital spaces.
Next, we 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 the following questions:

**Where does Alphabot live?**
**Where does Alphabot play?**

The interviewer coded the child’s response according to the following nomenclature scheme given each condition:

<table>
<thead>
<tr>
<th>Condition 1: Blended Reality</th>
<th>Condition 2: Virtual Blended Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>digital space</td>
<td>digital space</td>
</tr>
<tr>
<td>hutch</td>
<td>hutch</td>
</tr>
<tr>
<td>physical space</td>
<td>virtual physical space</td>
</tr>
</tbody>
</table>

*Please see Appendix B for complete diagrams*
In an effort to draw out the child's understanding of the hutch as an interreality portal and the transmediation of the character from physical reality to the digital space we asked them:

*What happens when Alphabot goes from “here to there”? (pointing at the diagram indicating physical and digital spaces)*

As a preliminary exploration into the ability for the children to recall and comprehend the symbols they used, we asked:

*What happens when you put a symbol on Alphabot?*

True to our guiding principle of ensuring that the experience we are creating (including the blended-reality environment and the blended-reality character) is co-designed with children's input, 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.

*What other things would you want Alphabot to do?*

Finally, we provided each child with an artist sketch book and a palette of colored markers. 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).
10.7 Results

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. Both incorrect answers came from five year old children. One negative answer came from a five year-old boy who replied there were four Alphabots and another from a girl who declined to answer - we chose to keep this answer in our data set as a negative or incorrect answer. A four year old boy who played in condition 2 (virtual blended reality game on-screen) replied that there were “5 to 100” alphabots, possibly referring to an imagined society of alphabots that lived in the fantasy world but had not yet come out to play. This may indicate that the child misinterpreted the question, but points to his strong belief in Alphabot’s synthesized world. Moreover, his answer underlines the capacity for the world to spark a myriad of imagined possibilities, a net positive result. 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.
Children's self-reported fun level across both experimental conditions by age:

![Bar chart showing fun levels across age groups and conditions](chart.png)

**Kid fun-level across both conditions**

In both conditions (1: Blended Reality & 2: Virtual Blended Reality), children reported an average of 3.625 based on responses using the smiley face assessment scale (SFAS). This pictorial scale ranges from 0 (least fun) to 4 (most fun). We found that although both genders had fun in both conditions, girls on average reported having 5% more fun than boys. In condition 1, girls had 7.5% more fun than the boys while in condition 2, girls had 2.5% more fun than the boys. These results suggest that the experimental setup succeeded at providing this thesis with a fair and strong comparison between both conditions. The blended reality condition and the virtual (video-game) version of blended-reality were equally enjoyable for the children studied.

Using the validated SFAS evaluation instrument, in condition 1: blended reality, the seventeen children scored on average 3.49. Girls had more fun with an average score of 3.67 while the boys average was 3.37.

In condition 2: virtual blended reality, the total population for this condition similarly averaged 3.77 with girls having slightly more fun based on their average score of 3.84 versus the boys average of 3.73.
Impact on imaginative play and character engagement

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.
Impact on imaginative play (post-play test verbal utterances transcript)

In condition 1, a seven year old boy wished Alphabot could play soccer and fly.

In condition 1, two children wished Alphabot could play tag.

In condition 1, a four year old girl suggested a wind-up Alphabot that would start dancing and jumping and could turn into other stuff like balls, chairs, tables and computers.

In Condition 1, a 6 year old boy wanted to build Alphabot a friend. He asked us to give Alphabot his drawing.

In condition 1, a four year old boy wanted Alphabot to go upside down (we presume he meant moving upside down in the digital world but we can’t be sure).

In condition 1, two children asked for more jumping.

In condition 1, an almost five year old boy wanted Alphabot to play with his owner and stated that Alphabot needed arms and legs.

In condition 1, a four and half year old boy replied that he wanted Alphabot to jump (we presume he meant in the real world, just like the character does in the digital space, although in this situation, we can not be certain).

In condition 1, one kid said he wanted Alphabot to pop up with legs.

In condition 1, a four year old boy wished that Alphabot’s Japanese friend could come out too.

In condition 1, a six year old boy wished there were more symbols. He also wished Alphabot would pop up with legs, arms and a face.
In condition 1, a boy declared, “I want you to put arms and legs so he doesn’t have to roll on wheels. We need to make his door bigger.”

In condition 1, a boy explained that he liked all the symbols but, “it would be cool to have a symbol for B and a face…a face symbol that makes Alphabot that face.”

In condition 2, a six year old boy wanted Alphabot to dance more.

In condition 2, a five year old boy wanted Alphabot to jump more.

In condition 2, a six year old girl wanted Alphabot to talk and dance.

_Child-assigned Alphabot fun level_
In condition 1, all seventeen children rated Alphabot’s fun at an average of 3.35 on a scale of 0.0 to 4.0 with 4.0 denoting the most fun possible. Girls rated Alphabot’s fun on average at 3.67 and boys rated the character’s fun at 3.9. In condition 2, the experimental population rated Alphabot’s fun at 3.47. Girls rated the character’s fun at 3.83 and boys rated it at 3.28 on average.

_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.

(The reader may want to refer to AppendixB for further clarification on the space nomenclature used to code the responses in both experimental conditions.)

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].
Where does the blended reality character live? (Condition 1)

- **digital reality**: 65% of the time, 82% of the time for boys.
- **robot hutch**: 35% of the time, 18% of the time for boys.
- **physical reality**: 0% of the time, 0% of the time for boys.

Where does the blended reality character play? (Condition 1)

- **digital reality**: 50% of the time, 36% of the time for boys.
- **robot hutch**: 31% of the time, 0% of the time for boys.
- **physical reality**: 19% of the time, 54% of the time for boys.
- **no answer**: 0% of the time, 0% of the time for boys.
Where does the blended reality character live? (Condition 2)

- Digital reality: 47%
  - Girls: 17%
  - Boys: 55%
- Robot hutch: 12%
  - Girls: 66%
  - Boys: 35%
- Virtual physical reality: 41%
  - Girls: 10%
  - Boys: 10%

Where does the blended reality character play? (Condition 2)

- Digital reality: 65%
  - Girls: 100%
  - Boys: 45%
- Robot hutch: 6%
  - Girls: 0%
  - Boys: 9%
- Virtual physical reality: 29%
  - Girls: 0%
  - Boys: 46%
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.

In condition 1, a four and a half year old boy explained that Alphabot jumps through.

In condition 1, a four year old boy exclaimed: “He takes a train to get from here to there!”

In condition 1, a five year old girl answered “noise.”

In condition 1, an almost five year old boy answered, “Alphabot goes behind the screen.”

In condition 1, a seven year old boy answered, “screen.”

In condition 1, a four year old boy offered, “He comes out of the green grass.”

In condition 1, a boy simply replied, “I have no idea how he goes from here to there.”
In condition 1, a boy explained, “Alphabot goes through a tunnel and then there’s a screen behind it.”

In condition 2, a six year old girl replied, “He changes himself!”

In condition 2, a six year old boy mentioned, “It's triggered by a symbol.”

**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).

In condition 1, an almost four year old boy answered, “it does the things that they to do.”
In condition 1, a six year old boy said, “we went to France.”

In condition 2, a five year-old boy said, “I forget” and then he said “The three, he counted” and “the heart he shouted out hearts.”

In condition 2, a four year old girl stated, “When I put a heart, it spreaded [sic] a lot more of hearts,” followed by, “When I did the musical, it was dancing.”

A six year old girl in condition 1 said, “with the number on, he said a funny sound” (referring to the number three triggering the Japanese counted numerals, “ichi, ni, san”).

In condition 1, a boy mentioned, “With the person it made a booming noise” (sound of the Japanese gong triggered by placing the Japanese symbol that looked like ‘a little person’ to the child).

In condition 1, a girl replied, “With the heart, lot’s of hearts came out.”

In Condition 1, a four year old boy asked, “Does Alphabot have a magic eye?”

_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.

*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.
Condition 1:

This girl drew the hills and fence of Alphabot’s digital world in the physical space. (right)

She also drew herself with Alphabot and a tree on a hill resembling the ones in the digital world. (below)
Condition 1: Other drawings made following blended reality play experiences.
A fairly complete depiction of blended reality drawn by a 5 year old boy following condition 1. We can clearly see the digital screen space, the hutch interreality portal, physical space, Alphabot and a human figure. The vantage point taken is unclear. We may be looking at blended reality from the inside of the world peering out through the screen at a self portrait of the child reaching for an “A”. Alternatively, the boy may have drawn himself into the digital screen space as a co-protagonist with Alphabot.
Condition 2: This boy drew an Alphabot with a smiley face and limbs:

This girl drew Alphabot, a dozen hearts, the Japanese friend and even the sound she heard. (left)
10.8 Discussion

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.
11 Potential as an informal learning tool

Considering the acceptance of Alphabot as a blended reality character and the evidence indicating its unique appeal to children three and a half to seven years old, further development of Alphabot’s potential as an informal learning tool is warranted.

The character, associated tangible symbol set and the novel context of play, have shown to arouse curiosity evidenced by children’s view of the Alphabot as a play puzzle to solve. The unique attributes of blended reality characters prompt children to question, investigate and explore the causal links between actions in the physical world and on-screen responses that seamlessly blend into the child’s environment. One of the older children tested in the blended reality condition asked, “Will you tell me how it works?” Leveraging the possibilities of a fully immersive experience wherein a constructionist learning environment can be seeded with purpose and children can tangibly participate in shaping a co-created blended reality world, sets the stage for educational interventions through ludic engagement [Pap80].

“I think something is wrong with Alphabot’s world. In the night it’s dark but the bees are flying around - they should be sleeping,” commented one perceptive boy. In as much as the character is appealing so is the environment. The system and initial experience provided present an opportunity for educators to shape the environment and context in which situated learning can take place. Leaving plenty of room for free play, a critical agent in the development of the whole child, the inclusion of an individually-tailored and adaptive curriculum could address the unique learning style of each child participant. The proven success of this type of approach can be seen in results from New York City’s Department of Education’s trial of the School of One system offering
personalized, individually-tailored instruction [Sch11].

In supplementary blended reality play tests with two or more children we noticed the reduced need for adult modeling as children worked cooperatively in a peer to peer informal learning scenario. They oriented towards the character and helped each other find and decide which symbol to test out next. It is my belief that the system works best when at least two children are interacting in it. Ultimately, the goal is to include remote play partners and increase global consciousness through shared and connected blended reality spaces.

Two children interviewed wanted to build Alphabot a friend. Using the knowledge and technical files shared in Appendix A of this thesis, an Alphabot assembly kit could be designed, empowering children to attain critical STEM and 21st century learning goals by assembling their own Alphabot and customizing its appearance, behavior and participation in a curated world.

Providing an interface for an adult caretaker or teacher could allow them to influence the play pattern and help scaffold the learning environment through indirect intervention. Overcoming the hierarchical adult/child dynamic and using a Vygotsky-inspired zone of proximal development model to, ‘level-up’ the blended reality world and its associated challenges, might result in a rewarding and fun learning experience for all involved.
12 Future Work

12.1 Further investigation
The observational data recorded uncovered several interesting phenomena prompting further investigation.

The fascination with the transmediation of the character as it bridges the fantasy and real worlds has yet to be fully understood. A longer-term study with multiple types of blended reality characters may help isolate the *interreality transit phenomena* from the design of the character. What is clear is that children have accepted blended reality characters as an extension of screen based media. What is yet to be known is why the kinetically and visually continuous change from a physical robot to an animated representation on-screen has so much appeal and plays an overwhelmingly central role in the children’s play pattern. Deeply considering this question could help inform the design of next-generation *interreality portals* and blended reality play experiences.

Several other examples prompt important questions regarding young children’s spatial reasoning and perspective-taking in this new context of play. Although almost two-thirds of the children who experienced blended reality play thought the character lived in digital space, the majority replied that it played in physical space. None of the children tested believed the character lived in physical reality despite touching and interacting with the physical robot. Furthermore, 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. For example, visual elements restricted to the screen or digital world of blended reality were drawn in the physical space section of the diagram provided. Another drawing by a five year old boy depicts the whole blended reality scenario seemingly from the inside out.
Additionally, blended reality character designers could benefit from a deeper inquiry on the observed gender-specific response with regards to where the children believe the character lives. Finally, a short-term goal should be to formally play test dyads of children in the system, building on observations recorded during the formative evaluation cycle.

12.2 Cross-media experiences
From this departure point, it would be fascinating to see how this scalable infrastructure and authoring pipeline could support next generation cross-media projects, connecting blended reality characters to a hub of specially designed, evolving content. As the system was designed to easily integrate with industry standard image, movie, geometry and sound formats, built atop open source inter-application glue, current media properties can be immediately ported over to this medium.

Imagine a successful informal learning tv show, created through the judicious balance of target audience needs assessment, formative research, the design of captivating characters and a healthy dose of fun, succeeding at changing the way millions of children around the world learn and play together. Connected toys and other tangible e-learning play sets would serve as input devices, allowing children to push content back into the screen. If an intended program segment is unable to attain its learning outcome goal with a particular viewer, rather than continue to the next segment, it would adapt to the viewer’s learning and play pattern, intelligently presenting the material in a manner best suited for the individual whole child’s healthy development and engagement.
Expanding on the initial work of the Neverending Drawing Machine’s creation station, viewers might be able to join a massively distributed, global arts and crafts atelier. In this new blended reality, everyday objects would not be treated as second-class citizens. Rather, they would be celebrated as artifacts of culture to be proudly shared amongst the empowered participants. Similarly, makers could share in the fun of composing collaborative, attention-dependent musical soundscapes.

12.3 Connected spaces
In order to connect blended reality spaces to each other, a procedurally generated, cloud-based rendering architecture could intelligently optimize overlapping bits of individual digital spaces, stitching them together into a perceived, cohesive whole. This would most likely be based on camera frustum culling techniques so what is not seen by the viewer is never computed, but transitions between spaces are accounted for in a networked, interreality traffic control hub. The Japanese Alphabot friend hints at remote location
possibilities. The current system can be easily extended to send symbol IDs from or to a remote Alphabot as well as stream blended reality world parameters paving the way for distance learning in collaborative play environments.

12.4 Character improvements

By design, the Alphabot is a simple robot and computer graphics character. Its proven acceptance and ability to maintain continuity across interreality boundaries, however, make it a very new and important class of character suitable for long-term companionship. In addition, its non-threatening and diminutive size, and wholly standard appearance as a box or modular alphabet block, invites a variety of uses. By moving the tangible input component, which in my opinion should remain as a core component of the design, to the top face (improving the ergonomics and making it easier to access) we make room for a front facing touch screen possibly equipped with a camera and embedded computational capabilities. This change would open up the possibility for perceived teleportation between connected remote spaces. Drawing something on a ‘Ms. Alphabot’ here, and sending it as a messenger to another place, would be easy as the user’s input could be digitized and uploaded to an accessible central repository of content, managed by a smart asset tracking system. The destination robot could emerge from its hutch in a different part of the world, displaying the sender’s drawing on its front face. This process could render visible the transmission and receipt of information, seamlessly blending bits and atoms.

Changes and improvements to the character itself could include more expression (an up/down degree of freedom), more autonomy if desired (although a semi-autonomous robot is a good choice), and the electro-mechanical and control software infrastructure enabling unfettered movement through an average household’s indoor and outdoor spaces.
12.5 Extended transmediation
The idea of a blended reality character has been accepted and shown to be appealing to children. An interesting direction of inquiry might be to probe the acceptance of the character long-term and across multiple forms of media. A new, possibly cloud-based robotics infrastructure would have to be implemented along with a persistent character database that learned user preferences and apportioned them between devices (e.g. mobile robot, smart phone, tablet computer, another mobile robot). Existing work in agent migration would serve as a useful jump-off point [Lir11][Syr09]. Also, designing an experience with a purely virtual version of the character at home could precede and follow blended reality play experiences.

12.6 New foundations
The hutch which now serves as the interreality portal could use several updates, starting with the ability to deliver multiple robots to its door, correctly orient them and host an efficient robot recharging mechanism.

The internal geometry of blended reality should be reconsidered so as to optimize computation and dynamically add on new spaces. The current physical space could be changed to use only two projectors overhead with large mirrors as well as a single back screen with a hole cut out the size of the hutch doors which themselves should be widened. The inclusion of a hidden, very rapid manufacturing device could allow the reconstitution of objects scanned in one space’s hutch and transmitted to another in a remote location. The exploration of different types of portals or hutches unconstrained by the ground plane could yield interesting results such as robotic bird hutches or hybrid new kinetic building facades with permeable walls.
12.7 Portals to learning

Installed as a series of physically and virtually connected blended reality experimental play spaces, an additional interreality portal to the outdoors could grant children special access to active learning and play opportunities. Inspired by the boy we observed trying to climb into the hutch in order to go through to the digital world, the provision of a kid-sized “rabbit-hole” leading to a concealed slide (or other device) that transitions the child to a well-planned outdoor environment, would afford the opportunity for educators and child development experts to design a curriculum around the choreographed use of these new types of indoor-outdoor spaces.

By in large, this fusion of indoor and outdoor activities already takes places in preschool environments. Future work could take a deeper look at how experiences in blended reality could spill over into discovery-based outdoor activities (e.g. studying the intelligence of a puddle, observing insects and flowers and experiencing the weather). We may find that instilling a sense of shared adventure between a blended reality character and a child to be an effective means to inspire and rouse curiosity. The transition between spaces, currently only available to the character through its portal, has already been shown to fascinate young minds. Providing a kid-exclusive portal might seed the young explorer’s consciousness with a healthy excitement for learning.

In turn, an outdoor robot, outfitted with different tools for outdoor play but designed to appear visually consistent with the indoor robot, would emerge from its outdoor hutch and accompany the child, possibly collecting samples together as they both explore and learn in the natural environment.
12.8 Making it accessible

As inexpensive 3d motion capture technologies become ubiquitous the possibility for bringing this experience into the home grows near. Localizing the robot in the home using an on-board, inertial measurement unit coupled with gesture recognition technology (similar to what the Microsoft Kinect sensor already provides), in concert with a robust hutch design and an internet-connected television or display, may be sufficient to bring this experience to life in people's homes. IPTV services offered in Korea, for example, provide interactive educational experiences that are impressive first steps, but remain screen-constrained. Bringing this experience into people's homes will require a tactful orchestration of multiple partners: telecommunications, media, toy and creative content providers could collaborate to create globally connected, home blended reality experiences. In the meanwhile, the experience, as is, can be replicated and installed in children's museums as an interactive exhibit. Another strategy would be to install systems like these in public libraries or civic spaces.

The simplicity of the Alphabot makes it inexpensive to replicate and customizable per geography and friend. Custom symbol sets can be easily added to the system with associated content. It is the author's hope that all children may one day have access to a system like this and be able to play and communicate with other children around the globe. The provided Do-It-Together kit is a great place to start. Have fun!
13 Appendix A: DIT source kit

Inspired by the Do-It-Yourself (DIY) movement, this Do-It-Together source kit invites groups of tinkering makers to recreate, improve, remix and share in the fun learning experience.

Blended Reality Touch source files for the environment can be found here:


Alphabot CAD files can be found here:

http://web.media.mit.edu/~lifeform/public_html/DIT/cad

Supplemental material can be found here:

http://web.media.mit.edu/~lifeform/public_html/DIT/other
The following spatial coding schemes were used to determine where the blended reality character lived and played in accordance with the children's answers given during the study's interview across both conditions.

**Appendix B: Spatial nomenclature**

Space nomenclature for Condition 1: Blended Reality

- Digital space
- Hutch
- Physical space
Space nomenclature for Condition 2: Virtual Blended Reality

digital space

hutch

virtual physical space
Appendix C: Alphabot design origins

(Above: illustration courtesy of Ryan Wistort, 2010)

The smart block holster is USB tethered to a computer. The Alphabot was conceived as a response to the idea that children using the above system would gain many advantages from connecting a tangible learning kit to a computer, but would most likely remain seated and thus sedentary during their play.

(Below: An alphabot family at play. Thank you HGSE T-530!)


16 Appendix D: Interview excerpts

“I want to come back and play with Alphabot.”

“I want to play with Alphabot’s friend in Japan.”
“When you are sleeping maybe he plays with his Japanese friends. And maybe he does that all night... maybe it’s a secret.”

(while drawing)
“I’m drawing an alphabet with eyes that we can see... it has magic eyes”

“His eyes are not real eyes, they are actually flowers.”

“Does Alphabot play sometimes with the other robots?”
(pointing at other robots in lab: Nexi and Maddox)
“Look, there’s Alphabot’s brothers and sisters!”
Interviewer: “Which ones?”
“The silver one and the white one are the sisters and the other silver one is the brother.”

“I think something is wrong with Alphabot’s world. In the night it’s dark but the bees are flying around - they should be sleeping.”

“Can we play with Alphabot now?” (after the interview)

“So maybe he’s not alive at night...” (as Alphabot retires to his hill in the digital space, the virtual sun sets and Alphabot ceases to move)
“I hope Alphabot sees my picture.”
“I’m drawing alphabets.”

“I want to see if Alphabot comes out again.”
Interviewer: “Do you want to give Alphabot your drawing?”
“How do you give it to him? Does he keep it in his grass?”

“Can we wake him up from his nap? Mom wants to see him.”

One child played with Alphabot in the real, physical world but once he transmediated onto the screen he yelled: “He IS real!”

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.

“Is that what he sounds like?” (it wasn’t obvious that the counting was coming from the Japanese friend)

“I don’t see Alphabot in the spot!”
Interviewer: “It’s a hill, maybe he went to the other side of the hill.”
“Yeah, maybe he’s taking a nap”

“Can we play with Alphabot again?”

“That’s his grass.”
17 Appendix E: Children draw Alphabot

Children from the B North preschool draw themselves with Alphabot. (Special thanks to the children and Professor Hiroshi Ishi for helping me with these images)
JASPER

"This is me with Alphabet"

E Z 10

Fluffy Gay

Alphabet Piece
LAUREN

This is us dancing with the mob.
Alphabet and me.
18 References

A


B


C


D


S


T


U


V


W


X

Y

Z
“We seem to know when to ‘tap the heart’. Others have hit the intellect... Those who appeal to the intellect only appeal to a very limited group” - Walt Disney