A Networked Suite of Mixed-Technology Robotic Artifacts for Advancing Literacy in Children

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ABSTRACT

Illiteracy is a global problem that impacts societal and economic growth and development, and is directly correlated with the financial success, health and overall well-being of individuals. Studies indicate that picture-book reading within a facilitated story-time setting is an important tool for language acquisition in children. We hypothesize that in an increasingly digital society, literacy can be cultivated in a robot-embedded environment that is, at once, physical, digital and evocative of the picture-book being read. Inspired by concepts of embodied interaction, our developing LIT ROOM is an intelligent, fine-tunable suite of architectural-robotic artifacts distributed at room-scale in a public library setting. Presented here are motivations for and design overview of this developing interactive artifact. Through a reconfigurable, co-adaptive learning environment, the LIT ROOM aims to augment the dialogical reading of picture-books within an engaging and exploratory space for the advancement of literacy and learning.

Categories and Subject Descriptors

H.1.2 [**Models and Principles**]: User/Machine Systems. I.2.9 [**Artificial Intelligence**]: Robotics. K.3.1 [**Computers and Education**]: Computer Uses in Education – *collaborative learning.*

General Terms

Design, Human Factors

Keywords

Computer Support Tools; Children; Emergent Literacy; Intelligent Environments, Architecture, Design; Human Factors, HRI.

1. INTRODUCTION

Illiteracy is an enormous problem, globally. Roughly 20% of the world's population is illiterate (UNESCO) [35]. In the United States alone, 14% of the nation's residents are illiterate; 32 million Americans cannot read the directions on a medicine bottle, and 50 million Americans cannot read above the 5th grade level (NAAL –the most current and continuous measure of adult literacy) [36].

In the LIT ROOM research project, we aim to demonstrate that literacy can be advanced within a specially designed mixed-technology environment that is at once physical and digital and evocative of the book being read. Coupled with its outreach mechanisms, the LIT ROOM concept introduced here will be designed and evaluated to augment the reading of picture-books within a collaborative, story-time experience situated in a large, regional public library setting.

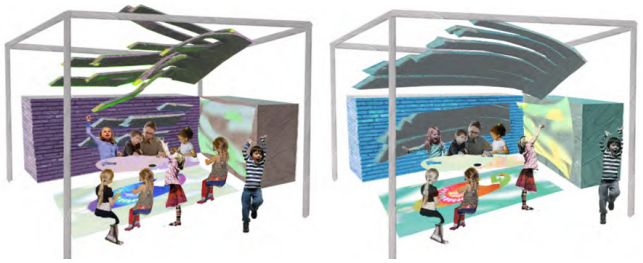

Figure 1. The LIT ROOM, transforming through co-creative, dialogical reading and exploration.

2. THE LIT ROOM INTERACTIVE ARTIFACT

In the proposed LIT ROOM (Figure 1), a suite of novel "architectural robotic" components distributed at room-scale responds to collaborative, environmentally-situated, story-book reading, transforming the book into the room, and the room into a book. The words of these young readers literally shape their physical surroundings, giving form to the book. If the form of the book offered by the intelligent environment fails to match the book as imagined by the participants, these young readers are afforded the opportunity, through the environment's tangible interfaces, to make visible and tangible their own perceptions for inspection by themselves and others. And by the same means, they can alter the course of the book, making visible and tangible different outcomes for their engagement and reflection. This active manipulation of the physical environment lends children a sense of ownership and control of their inner thoughts and their external surroundings, each one made to reflect the other. In this way, the participants invest in the book as both readers and editors.

2.1 The LIT ROOM Suite

The proposed LIT ROOM will include a suite of robots of mixed-technologies, including:

- Wall/ceiling-suspended continuum-robot surfaces employing tendons for their configurability;

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- a wall-mounted track for guiding mobile robot surfaces and/or objects;
- a set of identical modular robotic building blocks, each equipped with displays and sensors, and
- a collection of different modular robotic building elements, passive or with mobile capabilities.

The installation will also include reading tables sized to accommodate six children and one adult-guide, featuring interactive surfaces supporting, in particular, the modular robotic blocks employed as tangible interfaces (i.e. phicons [19]) for fine-tuning the system's intelligence. Integral to the system will be ICT components (e.g. sensors, digital projector, lighting, audio, a printer) as well as more conventional environmental-design components (i.e. the physical armature and frame of the environment, as required and desired beyond the given, existing library environment).

3. MOTIVATION FOR THE LIT ROOM

3.1 Literacy Support Tools & the LIT ROOM

Public libraries count the promotion of literacy skills as one of their primary missions [20]. Story-time in a structured learning environment, such as in a public library, is particularly critical for emergent literacy attainment. Children with limited access to early literacy materials at home, such as those children reared in poverty, have been shown to be at-risk for difficulties in literacy development [33]. Additionally, research indicates that mothers of low-income households, when engaged in dialogical reading with their children, are less likely to engage in instructive behaviors that truly contextualize the language [26].

Language growth and school achievement are directly related to early picture-book reading for young children [24]. Further, studies have shown that picture-books, because of their inherent balance between text and image, provide an opportunity for young children to contextualize verbal language in a way that enhances learning [33]. In collaborative story-time experiences, picture-books are often used to create a dialogical interaction between adults and children, and between a child and her/his peers, increasing the expressive language ability of children [39].

Recognizing the rapid advancements in ICT (Information and Communication Technologies), public libraries have increased their efforts to advance literacy skills in innovative ways that satisfy expanding definitions of literacy [20],[34]. Just as picture-books promote the contextualization of language by employing visual images, technological advancements have expanded traditional conceptions of literacy to include the space beyond the page of the book. Consequently, for the purpose of this research, we subscribe to the situational theory of literacy that places equal value on the tools for learning (e.g. books, devices or objects) and the physical environments within which individuals leverage those tools (e.g. [17]).

As ICT has expanded the context of learning into a richer variety of domains, a wide range of research has emerged to study how ICT-enhanced learning promotes literacy skills and motivates children [6]. Related more precisely to the LIT ROOM objectives, a segment of this literature is focused on how ICT-enhanced learning is supported through the collaborative reading of picture-books. Employing different sensing and interaction techniques, researchers have developed augmented books (printed and electronic) containing audio and video media aimed at spatializing the reading experience (e.g. [5]). Other researchers have explored the benefit of combining printed and e-books with computers, tangible interfaces, responsive toys, robots, and augmented-reality viewing devices (e.g. [16],[40]). "Story room" environments have utilized technology at the scale of the room to encourage authorship and collaboration between children by merging physical and virtual technologies (e.g. [1],[9]).

Although these state-of-the-art approaches to technology-enhanced contextual literacy education have aimed to merge the conceptual space of the book and the real space inhabited by the reader, these prior efforts, in comparison to the proposed LIT ROOM research, are limited by their physical size and scale, and by the specific technologies they employ. In "Augmented books," the scale of engagement is limited to the narrow-frame of the reader's immediate environment; the augmentation (the 3-D transformation) occurs only virtually, and is dependent on the use of cumbersome goggles or hand-held devices. Whereas "story rooms," occur in real space, their immersive impact (interactive imagery) is achieved primarily through the use of audio and cinematographic effects within an otherwise fixed environment [18].

In contrast to these prior efforts, the key to childhood learning in the LIT ROOM is a child's playful interaction with the people encountered, the digital and physical artifacts engaged, and the digital-physical environment that frames the event. While there is ample literature regarding literacy, learning environments, and the growing influence of technology on children, the literature on the important effects of the interactions of these domains has not yet emerged. Our research in child-robot interaction seeks to fill this gap by focusing on a reconfigurable, computationally-embedded, physical environment fostering literacy.

3.2 HCI Foundations for the LIT ROOM

The LIT ROOM has several key inspirations. First among these is Ishii's sentiment that "HCI design" suffers from "the lack of diversity of input/output media, as well as too much bias towards graphical output at the expense of input from the real world" [19]. In response, the LIT ROOM conflates the digital, physical and cyber spaces (see Figure 1). Secondly, the LIT ROOM finds inspiration in the concept of "Embodied Interaction" of Paul Dourish [14] and, specifically, Antle's concept of "embodied child-computer interaction" drawn from it. According to Antle, "meaning is created through restructuring the spatial configuration of elements in the environment" [2]. For the LIT ROOM, the reconfigurable nature of our robotic-embedded, physical environment makes it, in essence, co-adaptive, allowing environments and their inhabitants to change and develop. As Antle offers [2], "an environment . . . that supports multiple spatial configurations promises to advance a child's grasp of our universe through active, creative exploration." The arguments of Antle and Dourish are themselves supported by the child-initiated Reggio method of learning acquisition that long pre-dates them. The Reggio philosophy reminds us that "the environment is a teacher"; that the physical environment in which children learn is central to fostering their capacities [31].

As a robotics-embedded physical environment for children, the LIT ROOM is inspired, as well, by the "simulated environments" envisioned by Negroponte and the Soft Architecture Machine Group, imagined as "a living room that can simulate beaches and the mountains" [25]. The LIT ROOM allows for this transformation between the everyday environment of the library and the extraordinary environment imagined in books. Borrowing the words of William Mitchell, this transformation is achieved by way of "geographically distributed assemblages of diverse, highly, specialized, intercommunicating artifacts" that renders the physical environment a "a robot for living in" [23].

Generally, robots find a compelling application in child-focused domains for the "inherent attraction robots hold for most

children" [28]. In ways not un-related to the proposed LIT ROOM research, robots have been developed: to advance Science, Technology, Engineering and Mathematics (STEM) literacy in children; to improve child-robot interaction (e.g. [8]); and to cultivate letter recognition by way of an inexpensive consumer product, the Bee Bot [7]. The education of autistic children has been a significant focus of child-robot interaction research, which has demonstrated that the use of carefully designed robots can help focus the attention of autistic children (e.g. [15]).

With regards to human-robot interaction, and in a similar vein to Dourish's "embodied" thesis, the use of robots enables a bodily experience, forming tacit knowledge that anchors future learning. Learning arises in the interplay between bodily experience and conceptual insight [21]. Indeed, Papert describes robotic artifacts as "objects-to-think-with" [27]. In interacting with robots, children learn to explore new topics and to combine different bodily, participative and reflective approaches. In this way, children develop experimental and exploratory competences that promote multiple ways of learning [30].

More closely-related to the LIT ROOM ambition is research in child-robot interaction being developed by Cynthia Breazeal's group at the MIT Media Lab. In Playtime Computing [11], a playful robotic character seamlessly moves between its representation on a 2-dimensional screen and its materiality in the physical world, thereby "bringing children's media off screen" [12]. The LIT ROOM team is devoted to building upon this approach through the actualization of a digital-physical world embedded with a suite of interactive, reconfigurable robotic artifacts and environmental components in order to make the book visible and tangible at room-scale: the "artificial domestic ecosystem" of Negroponte, the "distributed robotics" of Mitchell, and what we have defined as "architectural robotics" [3]. In a novel way for HRI research, the LIT ROOM, as well, recognizes the pre-existing, persistent form and structure of the library environment itself, not as an obstacle to be overcome by creative and technological design, but instead, as a productive agent [22] providing its own code to the larger, complex physical-digital ecosystem [10] that is the LIT ROOM.

4. RESEARCH OBJECTIVES AND APPROACH

We believe the LIT ROOM will prove effective in cultivating the literacy skills of children in ways that are not only innovative, but also well-matched and relevant to the lives of children in a physical and increasingly digital world. These assertions find theoretical validation in the research cited here as well as in the "cycle of creative imagination" proposed by Vygotsky [38] which has informed HCI work in non-robotic learning environments [13].

4.1 LIT ROOM Goals

The objectives of the LIT ROOM project are:

- To iteratively design a technologically sophisticated robotic environment at room-scale that fosters literacy acquisition for at-risk populations in an increasingly digital society;
- to develop controls for a suite of mixed-technology (continuum and modular) robotic artifacts;
- to design a novel continuum (e.g. compliant) robotic surface employing tendons;
- to implement this robotic environment in-situ at a large public library to ensure children comfortably engage the technology;
- to evaluate the project through four iterative, formative evaluation cycles, one remedial cycle, and one summative cycle, and
- to extend the reach of this robotic environment beyond the confines of the public library by providing a series of outreach projects aimed at fostering literacy, enhancing participants' interest in STEM, and providing affordable mechanisms to bring robotics into classrooms and homes.

4.2 Research Approach

In Phase-1, we ask children to help decide what makes for a compelling LIT ROOM. We present to children, ages 4-8, low-fidelity "architectural robotic" artifacts within a library space to evaluate how children define and employ this digital-physical suite to "create the book." Several established methods will be used to evaluate the interactions of the children including observations, talk-aloud protocols, and active interventions [29].

In Phase-2, following from the feedback gained from the collaborative exploration, the team iteratively designs and evaluates (1.) the suite (as a fully-working environment), and (2.) the two associated outreach mechanisms. The same methods used in Phase-1 will be used to evaluate the fully-working environment. Educators and parents will be provided with the opportunity to assess the LIT KIT, and web analytics and a survey embedded in the interactive website will be used to evaluate the usefulness of these resources.

A future study will focus on the design of a functioning prototype for testing the critical components of the LIT ROOM with subjects (young readers with an adult-guide) in a laboratory setting. Initial findings from Phase-1 will be presented at the 2012 Interaction Design and Children conference.

5. LIT ROOM OUTREACH COMPONENTS

Children will be able to continue the LIT ROOM experience through an interactive website after leaving the library. Entering the website, users can design an online collage based upon their experience with the book. Similar cultural institutions have had great success with such projects [4], including the National Gallery of Art. The LIT ROOM website would also provide resources that include activities, lessons, and additional, topic-based content mirroring the LIT ROOM experience.

Expanding the interactive experience of the LIT ROOM, a "LIT KIT" will be designed for educators and parents for classroom and home use. To transport to the classroom/home the robotic aspect of the LIT ROOM, the KIT could employ an inexpensive microcontroller, powered by battery, as its computer, so that no laptop or desktop computer is required. Additionally, the KIT could include the same Sifteo [32] cubes used in-situ to reproduce the word-module aspect of the LIT ROOM in classrooms and homes.

The LIT KIT and the LIT ROOM together advance literacy by bringing books to life.

6. REFERENCES

[1] Alborni, H., Druin, A., Montemayor, J., Platner, M., Porteous, J., Sherman, L., Boltman, A., Taxen, G., Best, J., Hammer, J., Kruskal, A., Lal, A., Plaisant-Schwenn, T., Sumida, L., Wagner, R. & Hendler, J. "Designing StoryRooms: Interactive storytelling spaces for children." In *Proceedings of the Conference on Designing Interactive Systems (DIS-2000).* ACM Press, New York, 95-104, 2000.

[2] Antle, A.N., Embodied child computer interaction: Why embodiment matters. *interactions*, (March/April 2009).

[3] ARCHIBOTS, a Workshop on Architectural Robotics at Ubicomp 2009. www archibots.org.

[4] Arends, M., Goldfarb D., Merkl, D., and Weingartner, M. Interaction with Art Museums on the Web, In *Proceedings of the IADIS Int'l Conference WWW/Internet*, Rome, Italy, 2009, pp 117-125.

[5] Back, M., Cohen, J., Gold, R., Harrison, S. & Minneman, S. "Listen Reader: An Electronically Augmented Paper-Based Book." *In CHI '01*, pages 23–29, New York, NY, USA, 2001.

[6] Beastall, B. "Enchanting a Disenchanted Child: Revolutionising the Means of Education Using Information and Communication Technology and e-Learning," *British Journal of Sociology of Education* , Vol. 27, No. 1, pp. 97-110, Feb. 2006.

[7] Bee Bot by Terrapin, http://www.terrapinlogo.com/bee-bot.php.

[8] Beraza, I., Pina, A., and Demo, B., "Soft and Hard Ideas to Improve Interaction with Robots for Kids and teachers, *Proceedings International Conference on Simulation, Modeling, and Programming for Autonomous Robots*, Darmstadt, Germany, 2010, 549-557.

[9] Bobick, A., Intille, S., Davis, J., Baird, F., Pinhanez, C., Campbell, L., Ivanov, Y., Schutte, A. & Wilson, A. "The KidsRoom: A perceptually-based interactive and immersive story environment." *Presence: Teleoperators and Virtual Environments*, 8, 4, 367-391, 2000.

[10] Bratton, B. "The Convergence of Architecture and Interface Design. *Interactions*, (May/June 2008), pp. 20-26.

[11] Breazeal, C. "Playtime Computing," http://robotic.media.mit.edu/projects/robots/playtimecomputing/playtimecomputing.html.

[12] Breazeal, C. "Innovation Spot Light: Bringing Children's Media Off Screen", http://mitworld.mit.edu/video/819.

[13] Decortis, F., and Lentini, L. "A socio-cultural perspective of creativity for the design of educational environments." *eLearning Papers 1 N 13*, April 2009 www.elearningpapers.eu.

[14] Dourish, P. *Where the Action Is: The Foundations of Embodied Interaction*. Cambridge: MIT, 2001.

[15] Feil-Seifer, D.J. & Matarić, M.J., Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. *Proceedings 11th International Symposium on Experimental Robotics*, Athens, Greece, 2008.

[16] Garzotto, F. & Forfori, M. "FaTe2: Storytelling edutainment experiences in 2D and 3D collaborative spaces." *Proceedings of the 2006 conference on interaction design and children,* Tampere, Finland, 113-116, 2006.

[17] Gee, J. P. *Situated language and learning: A critique of traditional schooling*. London: Routledge, 2004.

[18] Interactive Educational Systems Design, Inc. (April 2010). *What the Research Says: How eamer Interactive Books Support Reading Comprehension and Content Knowledge Acquisition*. Lerner Publishing Group.

[19] Ishii, H. and Ullmer, B. "Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of the Conference on Human Computer Interaction* [CHI 97], 234-251, 1997.

[20] Lora, P. "Libraries and literacy in America 1985–2000." *Public Libraries* 29, 6, 354–362, 1990.

[21] Majgaard, G. Learning Processes and Robotic Systems – Design of Educational Tools and Learning Processes using Robotic Media and Children as Co-Designers. PhD dissertation, 2011.

[22] McCullough, M. *Digital Ground*. Cambridge, MA: MIT, 2004.

[23] Mitchell, W. J., *e-topia*. Cambridge, MA: MIT, 2000.

[24] Moerk, E. L. "Picture book reading by mothers and young children and its impact upon language development." *Journal of Pragmatics*, 9, 547-566, 1985.

[25] Negroponte, N., *Soft Architecture Machines.* Cambridge, MA: The MIT Press, 1975.

[26] Ninio, A. "Picture book reading in mother-infant dyads belonging to two subgroups in Israel." *Child Development*, 51, 587-590, 1980.

[27] Papert, S., *Mindstorms Children,Computers, and Powerful Ideas*, Basic Books, 1993.

[28] Pomalaza-Raez, C. and Groff, B.H., Retention 101: where robots go…students follow. *Journal of Engineering Education*, 92 (1), 2003.

[29] Read, J. and Markopoulos, P., C15: Evaluating Children's Interactive Technology. Course notes, *CHI Conference on Human Factors in Computing Systems*. May 7-12, 2011. Vancouver, BC, Canada, 2011.

[30] Resnick, M., et al., "New Pathways into Robotics: Strategies for Broadening Participation." In *Journal of Science Education and Technology,* 2008.

[31] Rinaldi, C. *In dialogue with Reggio Emilia.* London: Routledge, 2005.

[32] Sifteo cubes, http://www.sifteo.com

[33] Snow, C. E., & Goldfield, B.A. "Turn the page please: Situation-specific language acquisition." *Journal of Child Language*, 10, 551-569, 1983.

[34] Stephens, M. *Tame the Web: Libraries and Technology*. http://tametheweb.com.

[35] The Global Literacy Challenge, unesdoc.**unesco**.org/images/0016/001631/163170e.pdf.

[36] The National Assessment of Adult Literacy (NAAL) by The National Center for Education Statistics (NCES), http://www.independentmail.com/news/2009/jan/10/illiteracy-rates-among-adults-falls-south-carolina.

[37] The National Gallery of Art, http://www.nga.gov/kids/zone/collagemachine.htm.

[38] Vygotsky, L.S., Imagination and creativity in the adolescent. In R. W. Rieber, editor, *The Collected Works of L.S. Vygotsky*, volume 5: Child Psychology. Plenum, New York, 1998.

[39] Whitehurst, G.J., Falco, F.L., Lonigan, C.J., Fischel, J.E., DeBaryshe, B.D., Valdez-Menchaca, M.C., et al. "Accelerating language development through picture book reading." *Developmental Psychology*, 24, 552–559., 1988.

[40] Zhou, Z., Cheok, A. D., Pan, J. & Li., Y. "An interactive 3d exploration narrative interface for storytelling." *In IDC '04: Proceedings of the 2004 conference on Interaction design and children*, New York, NY, 155-156, 2004.