The LIT ROOM: Advancing Literacy in Children Through a Networked Suite of Architectural Robotic Artifacts

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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. The proposed research hypothesizes 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, the research team proposes the design, implementation and evaluation of an intelligent, fine-tunable suite of architectural-robotic artifacts – the LIT ROOM - distributed at room-scale in a public library setting. 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; Early Literacy; Intelligent Environments, Architecture, Design; Human Factors, HRI.

1. THE LIT ROOM
In the proposed LIT ROOM [7] (Figure 1), a suite of novel "architectural robotic" components distributed at room-scale responds to collaborative, environmentally-situated book reading, transforming the book into the room and the room into a book.

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The children are invited to become co-creators of their learning environment, their words, thoughts and critical reflections shaping their physical surroundings. If the form of the book offered by the environment's intelligence fails to match the book as imagined by the young readers, these readers are afforded the opportunity, through the environment's tangible interfaces, to make visible their own perceptions for inspection by themselves and others. These young readers can also alter the course of the book, creating 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. The LIT ROOM research, framed within critical theories of design, literacy, cognition, public library outreach and HCI, thus aims to cultivate 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 (Figure 1).

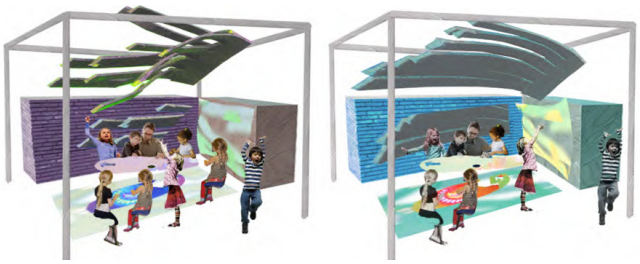

Figure 1. The LIT ROOM, transforming through co-creative, dialogical reading and exploration.

1.1 The LIT ROOM Suite
The proposed LIT ROOM will include the following suite of mixed-technology components:

1. Robotic components, including:
   - Wall/ceiling-suspended continuum-robot surfaces employing tendons for their configurability, and
   - A wall-mounted track for guiding mobile robot surfaces and/or objects;
2. Integral ICT components, including:
   - A wall-embedded touch-screen monitor that displays the electronic book and serves as the adult-guide's interface with the LIT ROOM suite, and
   - Lighting, audio and printer;
3. Conventional, environmental-design components, including:
   - A reading table accommodating six children and one adult-guide, and

   - A transportable and easily (dis)assembled frame for mounting the components of the LIT ROOM, and
4. Sifteo™ cubes [9] reconfigured as word-image blocks, the tangible interfaces used by children to interact with and fine-tune the system's intelligence.

2. RESEARCH OBJECTIVES

The objectives of the LIT ROOM project are:

- To iteratively design a technologically sophisticated robotic environment at room-scale that fosters literacy acquisition in an increasingly digital society;
- to develop controls for a suite of inherently-safe, continuum-robotic artifacts and multi-media environmental components (lighting and sound), which together transform the room into the book;
- to iteratively develop the two LIT ROOM interfaces: the Sifteo™ cube interface (for the children readers) and the interactive digital-book interface embedded in a touch-screen monitor (for the adult-guide);
- to implement this robotic environment in-situ at a large public library to ensure children comfortably engage the technology;
- to evaluate the project with respect to usability through four iterative, formative evaluation cycles, one remedial cycle, and one summative cycle;
- to evaluate the project with respect to literacy, specifically measures of vocabulary and comprehension, through two evaluation cycles, and
- to extend the reach of this robotic environment beyond the confines of the public library by providing two outreach mechanisms - an interactive website and a "LIT KIT" for home and classroom use, thereby providing affordable mechanisms to bring robotics into classrooms and homes.

2.1 Research Questions

The following questions will guide the LIT ROOM research design:

1. When compared to a traditional read-aloud experience, how does the interactive LIT ROOM impact measures of children's literacy, such as vocabulary acquisition and comprehension?
2. When compared to a traditional read-aloud experience, how does the LIT ROOM environment affect the way users engage within an interactive read-aloud setting?
3. How do children, librarians and educators rate the LIT ROOM on measures of usability, such as effectiveness, satisfaction and ease of use?
4. How do the individual components of the LIT ROOM suite, either separately or in combination, correlate with the various elements of language found in children's picture-books?

3. RESEARCH METHODS OVERVIEW

Phase-1, already underway, will focus on an iterative design process resulting in a low-fidelity LIT ROOM prototype. Phase-1 has four main objectives:

- To begin the co-creative design process where children help decide what makes for a compelling LIT ROOM;
- to develop strategies for the use of word/image modules (Sifteo™ cubes) as the tangible interface for the LIT ROOM components;
- to develop and test the "LIT KIT" outreach mechanism, and
- to develop a low-fidelity prototype of the LIT ROOM for a pilot study with subjects in a laboratory setting.

Phase-2, following from the feedback gained from collaborative exploration and the low-fidelity prototypes, will involve the iterative design and evaluation of the LIT ROOM suite (as a fully-working environment), and the two associated outreach mechanisms, both in a public library setting. Phase-2 of the research will begin after the receipt of grant funding, anticipated during the summer of 2013.

Elaborated here are the two interrelated activity streams, identified briefly and then discussed in detail, that define the LIT ROOM research plan for fully-realizing the aforementioned research objectives:

1. ITERATIVE DESIGN PROCESS: Iterative, human-centered design and evaluation of the LIT ROOM.
   a. Participatory process of establishing design specifications for LIT ROOM at RCPL test-bed.
   b. Iterative evaluation and implementation of the LIT ROOM at RCPL.
   c. Evaluation of LIT ROOM impact on measures of literacy and usability through a quasi-experiment.
2. TECHNICAL DESIGN: The development and testing of the architectural robotic components within the LIT ROOM system.
   a. Development of the core robotic elements of the full-scale functioning prototype.
   b. Development of the user interface specifications and their integration into the LIT ROOM prototype.
   c. Usability evaluation of the LIT ROOM system through a quasi-experiment.

3.1 Design and Usability

A mixed method approach (both human-centered and "creative"), as established by Mokhtar, Green and Walker for the design and evaluation room-scaled architectural-robotic environments [4], will be utilized to identify specific design requirements for the LIT ROOM system. Given the target population for the LIT ROOM, the evaluation strategy will be guided by the CHI 2012 Workshop Evaluating Children's Interactive Technology [6].

Upholding a human-centered design approach, where "the user should be involved throughout the design life cycle" in an "iterative" and "participatory" design process [11], groups of six 1st and 2nd grade children (ages 6-8), will be presented suites of low-fidelity artifacts made primarily of cardboard and/or foam that represent the LIT ROOM. This "creative" approach to research focuses "on functionality, aesthetics, and manufacturability simultaneously" [10][3]. Focus groups with the children, and separately with adult "experts" from the public library test-bed will be guided using physical scale models employing "WoZ" methods, where investigators simulate behaviors of an apparently fully-functioning system in anticipation of future, full-function development [e.g. 1].

With the input gained from the children's interactions with the various low-fidelity prototypes, early design concepts will be visualized initially as digital models for internal review; the outcome of these visualizations comprising a set of *design guidelines* for realizing the LIT ROOM system. Based on the established design guidelines, alternative concepts of the LIT ROOM will be explored in digital and physical scale-models, and as full-scale prototypes installed in a public library test-bed.

A series of sequential usability studies will be conducted on the LIT ROOM prototypes and subcomponents as they are being developed. Usability testing, as outlined by Nielsen [5] will be conducted through four iterative, formative evaluation cycles, one

remedial cycle, and one summative cycle, to assess that the LIT ROOM is both reaching task-effectiveness standards and operating effectively. Participating children will engage in talk-alouds, interviews, questionnaires and "draw your experience" protocols [6][12], to gain a sense of the functionality, the child-system interaction, and the overall quality of the read-aloud experience within the LIT ROOM.

3.2 Literacy Measures

The potential impact of the LIT ROOM on measures of literacy will be explored through a quasi-experiment in a public library test-bed. The experimental design will include assessments of four classes of approximately 24 1st-grade children, ages 6 and 7 – approximately 96 students total. From these classes, four groups of students will be determined by stratified random sampling with subjects selected for each strata based on literacy assessment data provided by participating schools.

Group 1 will participate in an initial, "traditional," interactive read-aloud session of approximately 20 minutes employing a narrative fiction picture-book. After the read-aloud session, students will be assessed through individual retellings methodologies and a brief interview. In a second session on a subsequent day, the same group of students will participate in a second interactive read-aloud session of 20 minutes, this time within the LIT ROOM environment, employing a comparable narrative fiction picture-book. Again, students will be assessed through individual retellings and a brief interview. To control for effects of treatment/control order, Group 2 will participate in the LIT ROOM first, followed by a traditional read-aloud. Groups 3 and 4 will follow the same procedures as Group 1 and 2 respectively, but the picture book will be a non-fiction text. To ensure consistency during sessions, adult facilitators will follow an interactive read-aloud protocol. A panel of literacy experts will evaluate the text selections to ensure comparability by rating the books on text difficulty, concept/vocabulary load, language, interest, and likelihood of familiarity.

Each student, at the end of each read-aloud, will be administered an assessment protocol involving a retelling and literacy interview. The two primary measures, retelling and comprehension questions, are well-recognized metrics for literacy comprehension [2]. Retellings are frequently used with varied age groups as an instructional approach, and as a measure to evaluate language, vocabulary and comprehension [9]. Following the retellings, students will be asked follow-up comprehension recall questions that correspond to the meaning of the picture books [9]. A team of trained Education graduate students will conduct the assessments to determine the child's skill in orally retelling the fiction narrative and the meaning/idea units of the non-fiction texts. In addition, key vocabulary of each text will be identified and emphasized during the session. Students will also be interviewed using a comprehension and interest questionnaire.

The one-to-one evaluations that follow will also include a usability interview to evaluate preferences and ease-of-use with respect to the interactive environment [6]. To control for the potential impact or novelty/"gadget effect" of the LIT ROOM, children will return to the RCPL one week later for a second retelling to determine extended recall of the texts.

3.3 Technical Design

Concurrent with the iterative design process, a primary component of the research design involves the development and testing of the continuum robotic components that populate the LIT ROOM suite. The evocative "palette" for the LIT ROOM environment will be provided by novel continuum-surface robot elements, enhanced by lighting and audio, that allow users to directly interact with the room through both a touch-screen monitor interface (for the adult-guide) and the Sifteo™ cube interface (for the participating children). The continuum elements will "morph" the environment surrounding the children (walls, ceiling and even floor) to reflect the atmosphere and/or "sense" of the book. Ceiling and wall elements will be designed to undulate to suggest, for example, clouds and hillocks. Wall surfaces will bend, and smooth projections will emerge from them to suggest the behavior of river currents. *Words become worlds*. To map the evocative continuum-surface configurations to the specific words that trigger them, we again invite the participation of children. Children visiting the public library test-bed for read-alouds over a one-month period will, at the close of their session, each take a 10 question survey asking the participant to map LIT ROOM physical configurations to corresponding key words that, collectively create the "vocabulary" of the interactive LIT ROOM environment. These collected preferences (n=250 minimum) will help guide the design of the overall, evocative LIT ROOM "palette."

In terms of the interface design, the Sifteo™ modules serve as a physical manifestation of images, letters and words, allowing children to communicate with the LIT ROOM by physically manipulating objects. A successful interface design will be a key objective for the LIT ROOM system, and usability testing will be conducted on the different interface designs to ensure that they are following principles to create a useable interface [11], including visibility, affordance and feedback.

4. CURRENT WORK

For an initial study, a low-fidelity prototype was created in a classroom setting for two 7-year old siblings, one boy and one girl, containing the following components:

- White sheets resembling the architectural robotic continuum surfaces, hung from the ceiling and walls for enclosure;
- a set of six foam-core cubes, intended to represent the Sifteo™ cube interface for the system;
- digital projectors, one projecting an image of the book being read on the front wall, and two others providing opportunities to enhance the "continuum surfaces" with light, color and image, and
- a table at the center, with three chairs and a physical copy of the book being read.

The children subjects were introduced to the aims of the LIT ROOM project, and were shown videos that illustrated the potential movements/transformations achievable by architectural robotic components and the functioning capabilities of the Sifteo™ cubes. The children were instructed to begin reading the book, and were asked after each page to describe if the LIT ROOM should transform, and if so, how they would like to see the components change to represent their understanding of the book. Initial findings from the co-creative study suggest:

1. Each of the "robotic" components and multi-media elements tend to contribute to the environment when the language in the book is in alignment with the specific affordances of each technology. For example, the children preferred to see a transformation in the continuum surfaces for spatial concepts (words such as "ceiling," "forest" and "ocean") and changes in motion (phrases such as "tumbled by," "be still" and "wild rumpus"). For the representation of characters (such as Max or the wild things) and objects (such as a boat or a stool), the children suggested using the Sifteo™ cubes or projected

images. Sound, color and image were suggested as enhancements to the robotic components, such as layering green onto the ceiling as the continuum surface transforms into a canopy of trees and vines, and layering in sounds of waves. The children found no instances where a single word or concept could be adequately represented by just one of the LIT ROOM components, suggesting the suite of components might be necessary to reflect the complexities inherent in most picture book environments.

2. Visual attention management will need to be addressed through the iterative design process. The children found it distracting to negotiate between the physical book and the projected book, and suggested the projected book felt more like it was a part of the LIT ROOM environment (the latest LIT ROOM design eliminates the physical book altogether).

Co-creative design strategies will be a critical part of all ongoing and future project phases.

4.1 The LIT KIT Outreach Mechanism

An initial prototype for the LIT KIT (Figure 2) was recently developed and evaluated for measures of usability. The kit, which employs lighting, sound and movement (robotic panels with paper streamers attached to the wall and/or ceiling), is controlled by a Sifteo™ cube interface. Both during and after children read a picture-book with their parent(s), they can customize the environmental effects, exploring concepts within the book through bodily, interactive and reflective approaches to the text.

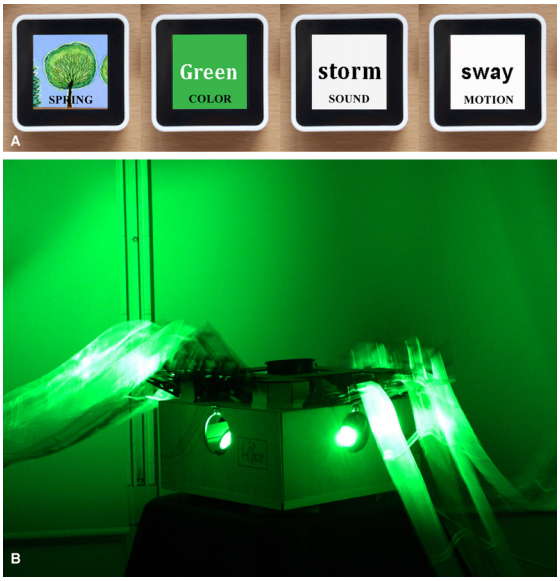

Figure 8. A: Sample custom option screens on the SifteoTM cube interface depicting some of the LIT KIT's environmental effects (color, sound and movement). B: The LIT KIT in action, with a child's customized choices producing green lighting, thunderstorm sounds and swaying streamer movements to represent the season of Spring.

A pilot study with 2nd grade children in a classroom setting is currently awaiting IRB approval. The research team will observe how children interact with the system, ask them to evaluate the KIT on measures of usability and fun, and interview educators to understand how the system can be improved as a tool for use during interactive read-alouds.

4.2 The LIT Room Low-fidelity Prototype

A low-fidelity prototype is currently being developed for use in an upcoming pilot study. The prototype will test the critical components of the LIT ROOM with subjects (two young readers, ages 4-8 and an adult guide for each test) in a laboratory setting, and will be evaluated for measures of usability using the methods described in Section 3.1.

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