Designing the LIT KIT: An Interactive, Environmental Mixed-Technology Robotic System for Enhancing Children's Picture-book Reading

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ABSTRACT

The product of a mutlidisciplinary and iterative process, the LIT KIT is a portable, mixed-technology architectural-robotic system for enhancing children's picture-book reading. The LIT KIT aims to scaffold critical literacy skills such as vocabulary acquisition, reading comprehension, and print motivation by creating a fun, interactive experience for children. Based upon the hypothesis that literacy skills can be advanced in an environment that is both physical and digital, the LIT KIT employs color, sound and movement to create an environment that is evocative of the picture-book being read. Designed with a Sifteo™ cube [24] interface, the LIT KIT, through room-scale environmental effects, acts to both contextualize language and provide feedback during dialogical interactions between a child and an adult reader. Additionally, children can customize the LIT KIT settings, allowing them to actively interpret the ideas, concepts and environments inherent in the picture-book's words and images. The LIT KIT is an outreach component, for home or classroom use, of the room-scaled LIT ROOM being developed by our research team for deployment in a major public library, Presented here are motivations for the KIT, and an elaboration of its design and evaluation.

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.*

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General Terms

Design, Human Factors

Keywords

Computer Support Tools, Children, Early Literacy, Read-Alouds, Intelligent Environments, Architecture, Design, Human Factors, HRI.

1. INTRODUCTION

In the United States, 14% of the nation's residents are illiterate, resulting in approximately 32 million Americans who cannot read the directions on a medicine bottle, and nearly 50 million adult Americans who are reading below the 5th grade (ages 10-11) level [26]. Additionally, a recent study indicates that 3rd grade (ages 8-9) reading proficiency is a leading indicator of high-school graduation rates, with children scoring low on literacy skills more than four times as likely to leave school [9].

Literacy is one of the primary missions of public libraries, and read-alouds are common programs provided by these institutions to scaffold children's early literacy attainment [14]. Picture books, both fiction and non-fiction, are commonplace in read-alouds with children. Whether at home or within the structured learning environments of schools and libraries, interactive read-alouds affords a rich opportunity for young children to advance language and literacy development [25]. A read-aloud experience that is both collaborative and situated in a physical environment conducive to learning encourages a dialogical interaction between adults and children, increasing the expressive and receptive language ability of children while allowing adult readers to adjust instruction to provide immediate scaffolding and feedback [18]. *Words become worlds*.

The developing LIT KIT (Figure 1), an outreach mechanism of the LIT ROOM [22] (Figure 2), aims to demonstrate that children's early literacy skills can be cultivated within a specially designed mixed-technology environment that supports dialogical

read-aloud interactions and is evocative of the picture-book being read.

Figure 1. The LIT KIT, transforming a child's room during a picture-book read-aloud with light, sound and movement.

1.1 The LIT ROOM Companion Research

The LIT ROOM [22], a room-scale suite of interactive, novel "architectural robotic" [4] components, is being developed by the research team to respond to collaborative, environmentally-situated picture-book reading in a public library children's room. The system, scaled to accommodate six children and an adult reader, includes robotic elements (continuum-robot surfaces), ICT components (touch-screen monitors, lighting and audio) and a tangible Sifteo™ cube [24] interface that facilitates children's active participation with the LIT ROOM.

The LIT KIT research supports public library literacy outreach by extending the interactive LIT ROOM read-aloud experience into homes and classrooms. Inspired by public library "storytime kits," thematic kits that contain books, manipulatives (such as puppets, felt board sets, games and toys), music CDs and activity guides, the LIT KIT brings learning-focused robotics into learning centers and homes. Scaling down the LIT ROOM experience presented the research team with a fundamental design question: how can a room-scale interactive environment be transformed into an economical, transportable system (Figure 2)?

Figure 2. The LIT KIT design challenge - how to fit the room-scale LIT ROOM experience into a small, portable format for in-home and classroom use.

2. MOTIVATION FOR THE LIT KIT

The LIT KIT finds inspiration in the concept of embodied interaction [7], where "meaning is created through restructuring the spatial configuration of elements in the environment" [3]. Because the LIT KIT offers a picture-book reading experience that supports multiple spatial configurations, we believe that it promises to "advance a child's grasp of our universe through active, creative exploration" [3]. The LIT KIT 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" [16]. The LIT KIT changes a home or classroom space into a robotics-embedded physical environment for children, allowing for the transformation between the everyday environment and the extraordinary environment imagined in books.

There has been a wide range of research into technology-enhanced learning to promote children's literacy skills, and in particular, the type of contextualized learning that is supported through picture-book reading. Related more specifically to the LIT KIT, researchers have developed augmented and mixed-reality books, both printed and electronic, that deploy different sensing, interacting and environmental technologies. For example, the Listen Reader [5] was designed to create an immersive environment for a child reading a picture-book through high-quality embedded audio triggered by sensing technology within the book. Expanding beyond the pages of the book, other researchers have added computers, tangible interfaces, responsive toys, robots, and augmented-reality viewing devices to deepen the book-reading and/or storytelling experience. One example, the Mixed-Reality Book [11] leverages both audio and visual technology to immerse a reader, with the assistance of a hand-held device and a desktop computer, in the book. Similar to the LIT KIT, the Mixed-Reality Book [11] also employs tangible interaction devices to encourage collaboration with the story. Finally, other researchers have merged physical and virtual technology at room-scale through the design of "Story room" environments, where children collaborate in authorship of narrative stories [1], [6].

Although these state-of-the-art approaches to technology-enhanced literacy education have aimed to bring the conceptual space of the book into the real space inhabited by the reader, these prior efforts, in comparison to the proposed LIT ROOM / LIT KIT research, are constrained by their scale and by the specific technologies they deploy. Augmented book experiences, such as the Listen Reader [5], limit the scale of engagement to the narrow-frame of the reader's immediate environment. While mixed-reality reading experiences (eg. [11]) engage children with digital and physical technologies and environmental effects, the augmentation (the 3-D transformation) occurs only virtually, and is dependent on the use of goggles or hand-held devices. Although "story rooms," occur in real space, their immersive impact (interactive imagery) is primarily achieved through the use of cinematographic and audio effects within an otherwise fixed environment.

More closely aligned with the use of Sifteo™ cubes to facilitate the interactive experience for the LIT KIT, TeleStory [12] is a language-learning application (vocabulary and reading comprehension) for pre-school children that also uses Sifteo™ cubes as the primary interface for collaboration and authorship. In TeleStory, children interact with a story that is visually represented both on the Sifteo™ cubes and a HD television. Children bring a story to life by making selections presented on the cubes, resulting in real-time visual transformations of the animated scene on the television. For example, by selecting a cube

depicting an image of the sun, the animated scene on the television transforms into a daylit environment.

In contrast to these prior efforts, the LIT KIT provides an opportunity for children to interact with digital and physical artifacts within a real, physical environment that transforms to contextualize the language in a picture-book.

3. DEVELOPING LIT KIT PROTOTYPES

Our research and design team is both multidisciplinary (architecture, robotics, library science and education) and multigenerational (professors and graduate students). Guided by faculty co-investigators representing the four participating disciplines, each of three groups of Architecture and Electrical and Computer Engineering students developed a unique concept for the LIT KIT, culminating in a functioning prototype. Each prototype was required to demonstrate its capacity to present one children's picture-book, and had to contain the following components:

- architectural-robotic elements resulting in a significant change to the home/classroom environment;
- controls (interface, such as Sifteo™ cubes [24]) for the system;
- microcontroller (and laptop, if required) for operating the system, and
- a branded container for the kit, which must contain the system in its entirety, instructions for use, and the picture-book being read.

Emphasis was placed on the durability and the design aesthetic of the system. Additionally, teams were encouraged to maximize the environmental impact of the system, focusing on how the LIT KIT, a system small and light enough to be transportable by one person using one arm, can transform a room-scale environment. While each LIT KIT design needed to scaffold literacy outcomes specific to their associated picture-book, the same design was additionally required to be adaptable to a wide-range of picture-books, both fiction, non-fiction. Teams had six weeks to develop a proof-of-concept (a functioning prototype), a scenario for its use, and a short, descriptive video for the system.

Teams worked within the context of a weekly graduate-level university course in Architectural Robotics [13], [4] during the Fall 2012 semester at Clemson University. Over six weeks, the multidisciplinary teams utilized rapid prototyping strategies, both low fidelity (physical study models) and high fidelity (virtual 3D models using various computer software), to develop the designs. The teams employed Arduino [15], an open-source electronics prototyping platform that is easily connected to actuators and sensors (Figure 3), such as servos and stepper motors, various sensors (pressure, PIR, infrared, etc.), and a set of Sifteo™ cubes [24]. The initial LIT KIT prototypes are summarized in the following sub-sections.

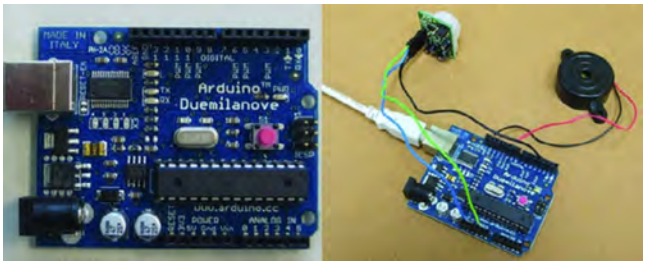

Figure 3. The Arduino platform [13].

3.1 Prototype 1: *Shadow Puppet Sound Box*

The "Shadow Puppet Sound Box" [2] (Figure 4) attempts to cultivate a child's understanding of onomatopoeia, or sound-words, through an interactive carousel with paper puppets. Paired with the picture-book "Old MacDonald Had a Farm" [19], the system casts shadows of various paper cut-outs (puppets) on the walls of a room where a parent is reading a picture-book to a child. The primary components of the system are a motorized (two servo-motor) carousel with transparent arms to hang various paper puppets, a system remote, LED lights, a speaker, one Sifteo™ cube, and an Arduino processing board. The Sifteo™ interface speaks to the Arduino processor via a laptop.

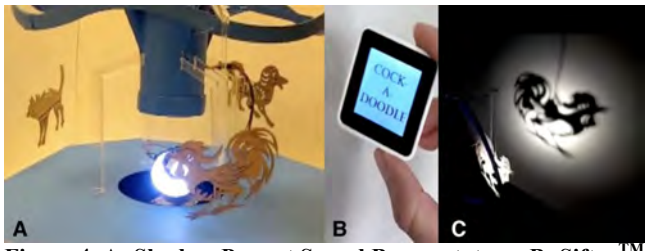

Figure 4. A: Shadow Puppet Sound Box prototype. B: Sifteo™ interface. C: Environmental impact as rooster shadow circles the room.

The following scenario describes how the Shadow Puppet Sound Box might enhance a bedtime picture-book experience for one child and his parent:

Dad and Bobby place the Lit Kit on a nearby dresser and first assemble the carousel by attaching the puppets to the transparent rods. Then, Dad begins reading the book. On page 1, Dad says: "Old MacDonald had a farm, ee-i-ee-i-o. And on that farm he had a rooster, ee-i-ee-i-o. With a cock-a-doodle here…" Dad presses the play button on the remote and the light on the puppet box starts spinning so that each animal casts a shadow on the wall as the light focuses on it. The Sifteo™ cube lights up showing the onomatopoeic word "cock-a-doodle." Dad asks Bobby: "Shake the cube when you can see the shadow of the animal that makes that sound." Bobby shakes the cube when the cat's shadow is cast, and a blue ring lights up around the perimeter of the Sifteo™ cube to indicate an incorrect response. Bobby then shakes the cube when the rooster's shadow is cast, and the ring around the cube turns orange, signaling a correct answer. Dad then presses the play button on the remote control and the carousel begins rotating so that the rooster's shadow appears to be moving around the room in celebration. The box also makes the real sound of a rooster, so Bobby understands the relationship between the image, the onomatopoeic word and the actual sound. Then Dad presses the remote to advance to the next page and the process is repeated for the remainder of the book (see video link [2]).

By simply changing the paper puppets, the word cues, and the sounds used, the Shadow Puppet Sound Box can adapt to any picture-book.

3.2 Prototype 2: *Picture It*

"Picture It" [10] (Figure 5) is an interactive experience that attempts to aid children in learning a second language. Paired with the picture-book "Chinese and English Nursery Rhymes: Share and Sing in Two Languages" [29], the system casts shadows of various cardboard stencils onto robotic panels containing IR sensors that are mounted on the walls of a room where a parent is reading a picture-book to a child. The primary components of the

system are a motorized (servo motor) carousel with LED lights, cardboard stencils with words, Chinese language symbols or numbers, a CD player, motorized wall panels, and an Arduino processing board.

Figure 5. A: Picture It prototype in use. B: Environmental impact with shadow cues projected onto robotic wall-panels.

The following scenario describes how Picture It might enhance an educational picture-book experience for one child and her parent:

Jingjie is a 7 year old child that is eager to learn Chinese. She goes to the library with her mother to check out a book called "Chinese and English Nursery Rhymes," which comes with the Picture It Lit Kit. The book has a selection of nursery rhymes in English and Chinese, which are also played as songs on an accompanying CD. After unpacking the Lit Kit and placing it on the floor in the center of Jingjie's room, Jingjie and her mother choose the nursery rhyme called "One Two Three Four Five." The four stencils associated with this rhyme (one Chinese symbol, one Chinese word, and two numbers) are then placed into the carousel. Three of the stencils correspond to the number four (4), and one does not. As they begin to read the rhyme and play the corresponding song on the CD, the Lit Kit begins to project the stencils onto the wall-mounted panels that Jingjie's mother placed around the room. During the course of the experience, Jingjie will be asked to move around the room and select the correct representations for the number four. To help her select the correct options, the robotic wall panels hint by moving slightly. As Jingjie touches a correct panel, the IR sensor activates the system and rewards her with flashing lights and a rotating screen. To continue the learning experience, Jingjie's mother simply replaces the stencils and selects the next rhyme (see video link [10]).

As with the first prototype, the system can be adapted to other picture-books by changing the cardboard stencils.

3.3 Prototype 3: *Living LIT KIT*

The "Living" LIT KIT [17] (Figure 6) is a multi-media system designed to be an abstract representation of a tree. Paired with the picture-book "Four Seasons Make A Year" [21], the system utilizes lighting, undulating paper streamers and sounds to aid in understanding of the unique characteristics of seasons. The Living LIT KIT can be positioned anywhere in a child's room, with streamers attaching to the walls and/or ceiling. The primary components of the system are a central cube with two hinged, motorized (servo motor) panels, paper streamers (attached on one of its ends to the panels and on the other of its ends to locations within the room), LED lights, a speaker (located in the laptop), four Sifteo™ cubes, and an Arduino processing board. The Sifteo™ interface speaks to the Arduino processor via a laptop.

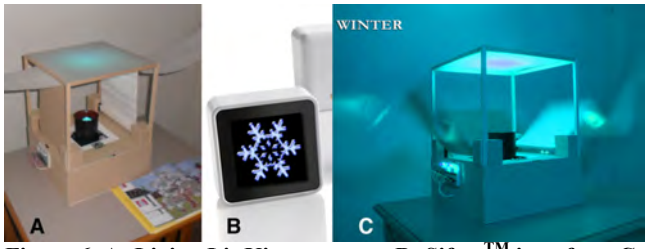

Figure 6. A: Living Lit Kit prototype. B: Sifteo™ interface. C: Environmental impact with lighting and streamers activated.

The following scenario describes how the Living Lit Kit might enhance the reading of a picture-book in a child's room:

Jimmy and his mother are lying in bed reading the book "Four Seasons Make A Year." As his mother is reading about the first season in the book, "Spring," the Sifteo™ cubes reveal four images, each representing one of the four seasons. Jimmy's mother asks him to press on the cube that represents something that he would see during Spring. As Jimmy presses the image of the flowers in bloom, he first hears the sound of rain and birds chirping in the room. Jimmy then notices that the lighting in the room starts to change to the colors of violet and blue. Additionally, the panels on the LIT KIT begin to sway slowly, causing the streamers to undulate to represent a gentle breeze. This helps Jimmy associate spring with sounds, colors and movement on an experiential level and at an environmental scale. Jimmy and his mother keep reading, and with each season notice the different environmental cues. Autumn, for example, is represented by orange lighting, the sound of rain, wind and falling leaves, and by faster, more sporadic streamers. The different scenarios help Jimmy associate seasonal concepts with experiential characteristics that expand beyond the two-dimensional representations in the book (see video link [17]).

As with the other prototypes, the system can be adapted to other picture-books by changing the Sifteo™ program and the associated sounds, colors and movements.

4. EVALUATING THE PROTOTYPES

After the six-week design and prototyping phase, the research team evaluated the three LIT KIT options in order to identify one prototype to develop further into a more robust, refined LIT KIT. A heuristic evaluation [20] was carried out in the Clemson Univerisity Architectural Robotics laboratory. Each design was presented in video format followed by a physical demonstration of the prototype. After each demo, the research team (excepting the team members responsible for the design and development of the specific prototype being evaluated) completed a questionnaire that rated the prototype on measures of usability, environmental impact, aesthetic design and reading motivation/engagement. The participants were: nine graduate students – four females and four males, ranging in age from 24 to 42 years old (mean age, 29 years old); and two male professors, ages 49 and 50 years. Eight evaluations (n=8) were completed for each prototype.

For the evaluative questionnaire, the research team developed an instrument specifically designed for first grade children, ages 6-7 (the intended age range for participants in a Phase 2 evaluation of the LIT KIT). The design of the instrument was guided by established protocols for evaluating interactive technology for children as outlined in the 2011 CHI workshop [20]. The questionnaire utilized the "Smileyometer" [20], a graphic representation of the traditional 1-5 Likert scale using faces that illustrate varying levels of approval. For the heuristic evaluation,

the research team served as proxy children, piloting the questionnaire in order to both confirm its validity as an evaluative instrument and its appropriateness for future use with children subjects. Figure 7 illustrates the graphic representation for each face along the scale, as well as the verbal answer associated with the faces for each type of question (such as prompts beginning with "what did you think about," "how easy," and "how much").

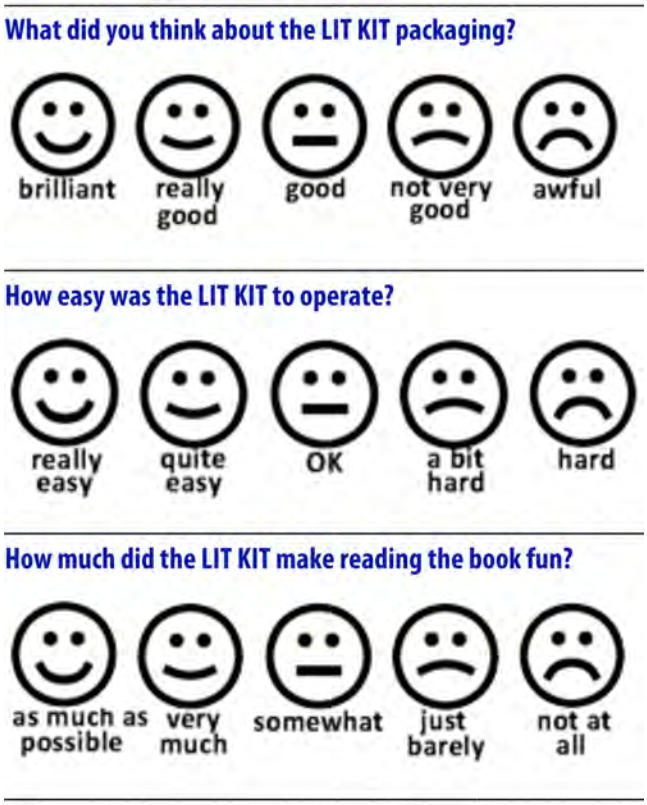

Figure 7. "Smileyometer" [20] questionnaire instrument.

The following questions, sorted by evaluative categories, were included in the questionnaire:

- For measures of usability:
  - How easy was the LIT KIT to assemble?
  - How easy was the LIT KIT to operate?
  - How easy would it be to explain how to use the LIT KIT to one of your friends?
- For measures of environmental impact:
  - How much did the LIT KIT feel like a game or toy?
  - How much did the LIT KIT change the room's environment?
  - How much did you like the way the LIT KIT changed the room's environment?
- For measures of aesthetic design:
  - What did you think about the LIT KIT packaging?
  - What did you think about how the LIT KIT system looked when it was assembled?
- For measures of reading motivation / engagement:
  - How much did the LIT KIT help you to understand the book?
  - How much did the LIT KIT make reading the book fun?
  - How much would you want to use the LIT KIT to read another book?

A post evaluation analysis of the questionnaire data revealed the third prototype, the Living LIT KIT (Figure 6), to be the highest rated system by the research team. Figure 7 shows the four main evaluative categories along with the respective mean for each prototype design. Overall, the results indicate a positive evaluation for each of the three prototypes, with the Living LIT KIT mean scores differing most significantly from the middle of the scale (represented by a score of 3). Additionally, the Living LIT KIT utilized the Sifteo™ cube interface in a manner most closely related to what is envisioned for the larger LIT ROOM suite.

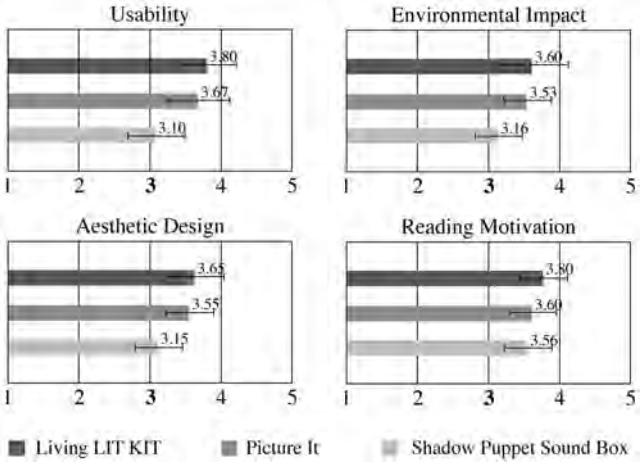

Figure 7. Questionnaire results per evaluative category.

5. REFINING THE LIT KIT

After choosing the Living LIT KIT prototype for further development, our larger research team identified overall goals for the system. First, a refined system must be durable (robust). The initial prototypes were primarily constructed using inexpensive, available materials such as cardboard and paper, and would not have sustained multiple demonstrations. As the LIT KIT is intended to be checked-out from a public library for use in private homes and classrooms,, sturdiness and durability are of critical importance. Secondly, the system must be easy to operate and aesthetically pleasing. A beautifully designed system, with simple, straightforward instructions, would entice children, parents, librarians and educators to want to use the LIT KIT.

Additionally, the refined LIT KIT would need more variation in how the paddles and streamers moved, particularly if the movements and environmental effects were to be evocative of the wide range of concepts represented in children's picture-books. (A critique of the initial design was that the paddles *appeared* to move in unison, at the same speed, range and frequency). So while the initial prototypes was programmed to offer environmental effects primarily with respect to one book, the refined LIT KIT must offer a wider-palette of effects to enable it to operate effectively *with any picture-book available in a public library*.

In order to test the applicability of the system across different types of picture-books, a second book was carefully selected by the four faculty investigators for being very different from the book used in the earlier prototype. This second book was the non-fiction "Underground" [8], a picture-book describing the history of the underground railroad, that employs evocative images and minimal language to chronicle the journey of slaves from captivity to freedom. The choice of this book allowed the team to

explore how the LIT KIT's environmental effects (light, movement and sound) might evoke not only the physical phenomena (trees, wind, rain, etc.) presented in the "Four Seasons," the book demonstrated with the earlier Living LIT KIT prototype, but also feelings and emotions as evoked by the "Underground" (fear, sadness, happiness, etc.).

Finally for the refined prototype, the Sifteo™ cube interface should be further developed to more specifically scaffold literacy outcomes (such as vocabulary development and reading comprehension) and allow for customization of the system. Using the Sifteo™ interface, the *children* themselves should be able to program the LIT KIT to create the types of environmental effects that match their imaginings and/or understandings of what they are reading.

After establishing overall goals, our research team assembled into three groups responsible for advancing specific areas for refinement. One group focused on the LIT KIT packaging, including the design of the system container, the graphic representation and branding for the kit, and the printed instructions accompanying the system. A second group was specifically responsible for the construction and the design of the motorized artifact, including the refinement of all moving parts and lighting components. The third group further developed the Sifteo™ interface. The refined LIT KIT was developed over four weeks.

5.1 Packaging / Branding Refinement

The refined LIT KIT "container" was constructed out of plywood (Figure 8). The base contains the mechanical components (LED lights, power cords, Arduino processing board, etc.), and is flush with the LIT KIT lid. The lid, which has a handle on the top surface for user-friendly transport of the system, attaches to the base on four sides by clasps, and contains a drawer compartment at the top that houses the Sifteo™ cubes, picture-books, and the instructions specific to each book (Figure 8A). General use instructions, etched onto one of the sides of the lid, offer users the necessary information concerning how to remove the contents of the drawer, how to remove the lid, where to locate the LIT KIT in a room and how to operate the system. A playful LIT KIT logo is also etched into the sides of the container, along with a graphic representation of the fabric streamers that playfully suggests the experience that awaits young readers inside the kit (Figure 8B).

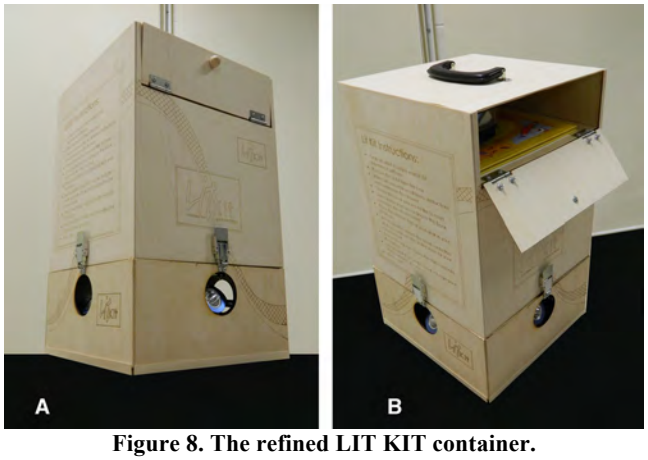

Figure 8. The refined LIT KIT container.

Each picture-book is accompanied with specific instructions for parents and educators, including suggested spoken prompts that adult guides (parents, teachers) might offer children during the read-aloud experience (Figure 9). The instructions also indicate the optimal placement for the fabric streamers, depending on the book being read. For example, for the book "Four Seasons Make A Year" [21], the suggested arrangement of streamers is intended to represent the branches of a tree (Figure 9A), while for the "Underground" book [8], the streamers are to be clustered to evoke a group of people moving from captivity to freedom (Figure 9B). In the "custom setting" for the LIT KIT, children and parents are encouraged to explore alternative placements for the LIT KIT system to more accurately reflect their interpretation of the picture-books.

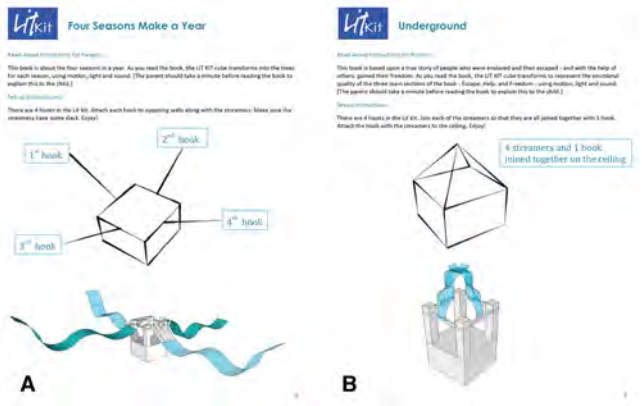

Figure 9. A: Instruction page for "Four Seasons Make A Year." B: Instruction page for "Underground."

5.2 Mechanism / Design Refinement

Refinement of the overall system and its mechanical components focused on three primary concepts: increasing durability, maximizing variability in terms of the environmental effects created by the system, and aesthetic appeal. For durability, the refined system used more robust motors, gears and threaded rods to facilitate the movement of the paddles. This change made an impact on the overall size requirements for the container as well as the weight of the system. The paddles, originally constructed of cardboard, were replaced with individual wood-truss fins mechanically attached with nuts to a threaded rod at the base. Additionally, the LED lighting components, exposed on the outside of the original prototype, were recessed into the system base, both for increased environmental impact and durability (Figure 10A).

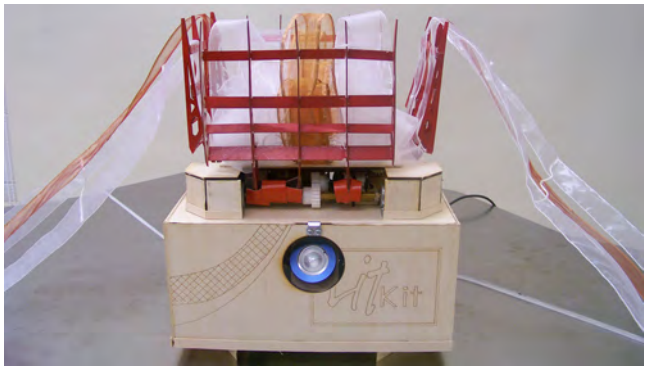

Figure 10. The LIT KIT mechanism and streamers.

The streamers were refined as well, changing from crepe paper material in the first prototype to a series of translucent, fabric ribbons for the refined LIT KIT. The streamer length and

wall/ceiling attachment mechanism were designed to accommodate multiple set-up scenarios. The research team considered a streamer length of 12 feet to be adequate for most home or educational settings (while not being too long to easily fold into the system container). After the first 6 feet of streamer length, grommets were provided at 6 inch intervals to the end of each streamer, allowing them to be easily attached to removable wall-hooks at multiple lengths. Streamers are also attached at the paddles using Velcro™, allowing for simple detachment and replacement.

To increase the variability of the system, the design team added two additional paddles and streamers to the LIT KIT system. With four paddles, both the environmental effects and the potential variety of movements could be maximized. In the original prototype, the paddles moved in unison, generally through the same range of movement and at the same speed. Aside from the change in color and sound, the difference between the "Spring" and "Summer" settings, in terms of movement, were subtle. The research team, however, wanted the LIT KIT to be a system that could express, at a larger, environmental scale, a wide range of concepts, experiences and phenomena, and more importantly, display different movements that are visually discernable. With four paddles, variation could be achieved by having all or some (or even none) of the paddles moving simultaneously. Additionally, the design team developed variations in range (how much the paddle moved within the possible 90° range of motion), speed, and sequencing (Figure 11).

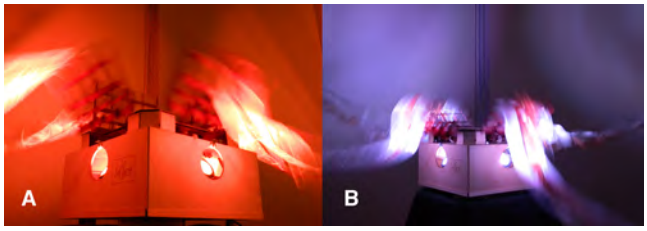

Figure 11. A: Fall "shake" movement. B: Winter "bend" movement.

To guide the various movement settings, the design team developed a list of descriptive words, and programmed a unique paddle movement setting for each. Overall, sixteen unique movement settings were programmed into the refined LIT KIT, correlating to specific word descriptors such as "sway," "undulate," "shake," "collapse," "soar," "twist," "flop" and "rotate." In the customizable setting for the system, children will be able to choose among these words to "program" the environmental effects they believe best represent concepts from the picture-books, further scaffolding analogical language development.

5.3 Sifteo™ Interface Refinement

A novel contribution of the LIT KIT research is the use of the Sifteo™ cube interface to communicate with the Arduino processor, and thus control the actions of a multi-media, architectural robotic artifact. In both the prototype and the refined version, a text file on a laptop served as the intermediary between the Sifteo™ and Arduino systems (shown as a flow chart in Figure 12). In this process, the Sifteo™ program writes to a file each time a desired action is taken with the cubes. Then, code using the integrated development environment (IDE) reads this file and sends new information through serial communication, over a USB port, to the Arduino board. The information in the text file can be as simple as a number or a letter. For example, in the context of the book "Four Seasons Make A Year," the number one (1) could represent the season "Spring." When the child-user clicks the cube picturing the image of a Spring tree, the Sifteo™ program writes a one (1) to the text file. IDE, checking the file on scheduled intervals, reads the one (1) and sends it to the Arduino board. The code in the Arduino board recognizes the one (1) as a representation for "Spring" and produces the pre-programmed command for the LIT KIT artifact for that input. The process is repeated as many times as required for the picture-book being read.

Figure 12. Sifteo™ / Arduino communication diagram.

For the initial Living LIT KIT prototype, the Sifteo™ interface only acted as a single control to produce all of the environmental effects (sound, light and movement) for each associated season. A child-user would simply press the representational image of "Spring" and the LIT KIT would transform the environment as a contextualization of that concept. For the refined LIT KIT, the design team wanted to leverage the interface to further assist in the types of literacy skills, such as vocabulary development and reading comprehension, that occur naturally during a picture-book read-aloud [28]. Specifically, the refined system allows the child-user to layer in some or the environmental effects in stages, increasing the interactivity and language development. Pressing the cube with the Spring tree activates the light and movement (both embedded within the system itself) (Figure 13A). In order to add sound, the cubes depict images and words directly from the picture-book (such as a bird, and the words "buzzes," "blows," "falls" and "sings"), which must be correctly paired in order to activate the Spring sound. In this case, the child would place the bird cube next to the "sings" cube to correctly layer the sound into the environment (Figure 13B).

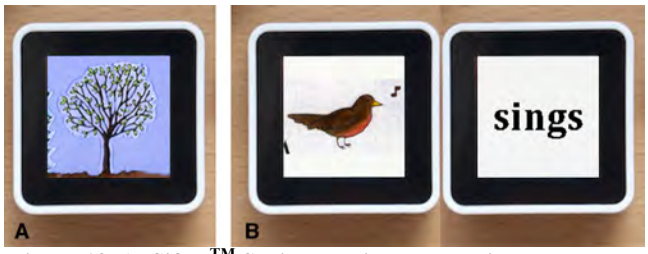

Figure 13. A: Sifteo™ Spring tree image to activate color and movement. B: Sifteo™ text / image pairing to activate sound.

In order to encourage active learning and reflection, the refined LIT KIT system should also be customizable, thus allowing children to "experience, construct, test and revise knowledge" [27]. If after the first reading of the picture-book (which includes the pre-programmed sounds, lighting and movement effects), the child-user elects to interact with the system as author and designer, the system offers a custom setting to accomodate this. For each picture-book, one Sifteo™ cube acts as the system master cube, initiating specific program options (pre-programmed programs and custom programs). For example, the master Sifteo™ cube for the refined LIT KIT has six program options:

three for the "Four Seasons Makes A Year" book ("Standard," "Custom" and "Set-Up" - Figure 14), and the same three options for the "Underground" book. Pressing the "Standard" menu option activates the pre-programmed experience for both books and pressing the "Custom" menu option activates the customized experience.

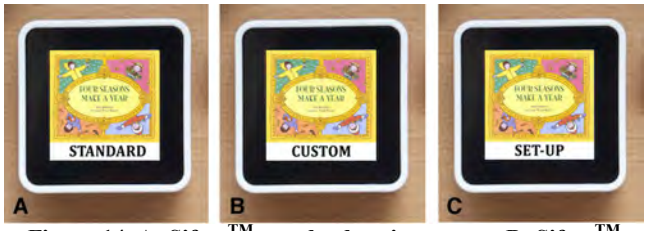

Figure 14. A: Sifteo™ standard option screen. B: Sifteo™ custom option screen. C: Sifteo™ custom set-up screen.

In order to program the custom LIT KIT experience for the "Four Seasons Makes A Year" book, for example, the child user would press on the "Set-Up" menu option for that book, and he/she would then be able to choose from a library of sounds, colors and movements to create a custom representation for each season. To choose a "Summer" lighting color, for example, the first color in the library, "green," would appear on the Sifteo™ cube for color choice. When the color appears on the cube, the LED lights on the LIT KIT activate to contextualize that choice. Pressing on the color cube then advances to the next color, which in turn changes the color on the LIT KIT artifact. The last color pressed by the child is saved to the custom setting for the season being programmed. The child can also choose sounds and movements in the same manner (Figure 15A).

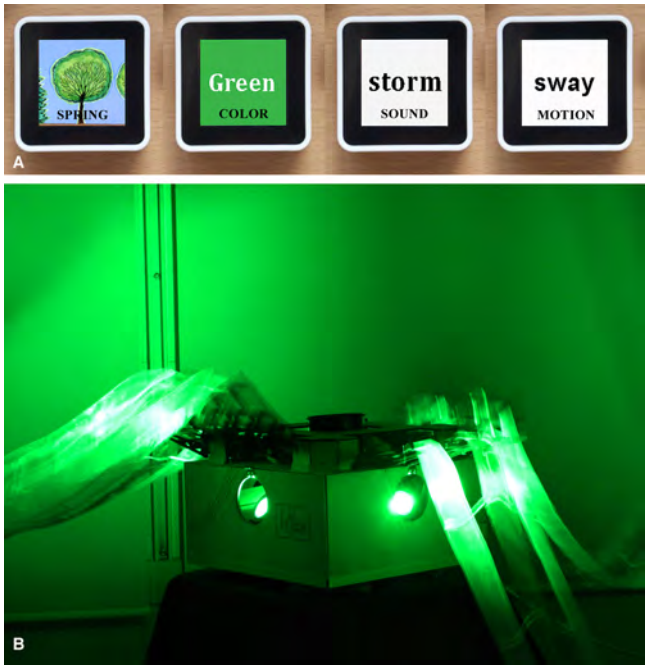

Figure 15. A: Sample custom options for the "Summer" environment. B: Choices depicted would produce green lighting, thunderstorm sounds and swaying streamer movements.

Pressing the cube depicting the Summer tree saves the custom settings for "Summer" (Figure 15B), and the process moves on to the remaining seasons. After the last season is customized, the settings are saved, and the child and parent/educator can read through the book again, this time with the different, personalized effects.

5.4 Refined LIT KIT Scenario

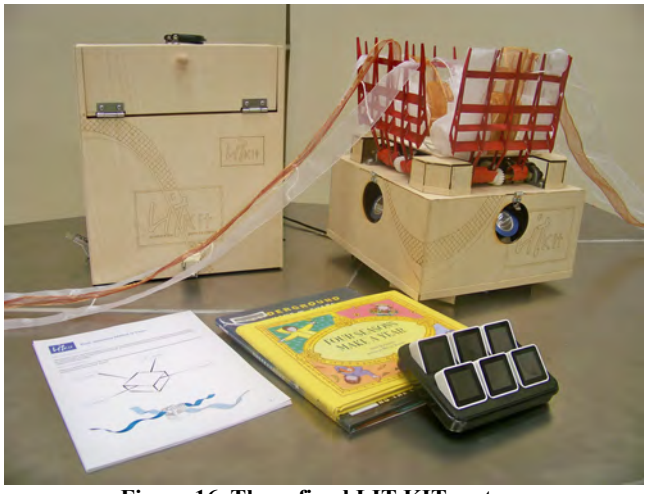

Figure 16. The refined LIT KIT system.

The following scenario describes how the refined LIT KIT (Figure 16) might enhance the reading of the "Underground" [8] picture-book in a child's bedroom:

One day while Sam was visiting the children's room at his public library, he had an amazing story-time experience in an interactive space called the LIT ROOM [22]*, where the environment transformed into the book. The LIT KIT was designed so Sam could have a similar experience in his home or classroom, so he checked it out from the library that afternoon. At home in his bedroom, Sam and his father read the instructions on the side of the LIT KIT. They then open the drawer at the top of the LIT KIT and remove the picture-book entitled "Underground," which chronicles a group of American slaves and their journey along the Underground Railroad - from captivity to freedom. After removing the system instructions and the Sifteo™ cubes, they unlatch and remove the cover, and Dad places the LIT KIT mechanism on a nearby desk or chest in Sam's room* (Figure 1)*. Dad plugs the LIT KIT power cord to a nearby outlet and turns on the laptop included with the system. Dad also places the Sifteo™ cubes adjacent to the "Underground" picture-book next to Sam, and begins to read the instructions for the book, which explain:*

"This book is based upon a true story of people who were enslaved and then escaped - and with the help of others, gained their freedom. As you read the book, the LIT KIT transforms to represent the emotional quality of the three main sections of the book - Escape, Help, and Freedom - using motion, light and sound. As you begin, you will see a control cube which has a picture of the 'Underground' cover and the word 'Standard.' Press this cube and the three other cubes will reveal images from the main sections of the book: one expressing 'Escape," one depicting 'Help' and the third illustrating 'Freedom.' Your child will use these three cubes to interact with the LIT KIT during the reading experience. [The parent should take a moment before reading the book to explain this to the child.]"

When dad has finished explaining the overall concept of the book and the purpose of the LIT KIT and interface cubes, he and Sam attach the four streamers to the ceiling as illustrated in the

instructions (Figure 9B). *He then begins reading the book aloud to Sam, continuing to follow the instructions:*

"ESCAPE:

1. *On the second page of the book you will see an image of people escaping in front of a building . Upon reading the words, 'The escape,' ask your child to look at the Sifteo™ cubes and press down on the image that represents 'Escape.' If your child chooses incorrectly, the cube will change to depict the word associated with the wrong choice, such as 'Freedom.' Direct your child to choose until he/she pushes the cube with the image depicted on the 'Escape' page. A correct answer will activate the LIT KIT!*
2. *After pushing the correct image, the Sifteo™ cubes should now show the image of running feet, along with two choices of words that express emotions. Continue reading.*
3. *When you get to the illustration that depicts people running, upon reading aloud the words 'We run,' ask your child: 'Do you see the image of the people running? How would you feel if you were running away from something you were trying to escape? Can you put the cube that shows the running feet together with a word that expresses that type of feeling?'*
4. *When your child puts the cube showing the running feet next to the cube that reads 'afraid,' the LIT KIT will play the sound of a group of people running. After the LIT KIT stops moving and making this sound, begin reading the book where you left off. (At this time, the Sifteo™ cubes will again show images of the three sections: Escape, Help and Freedom)."*

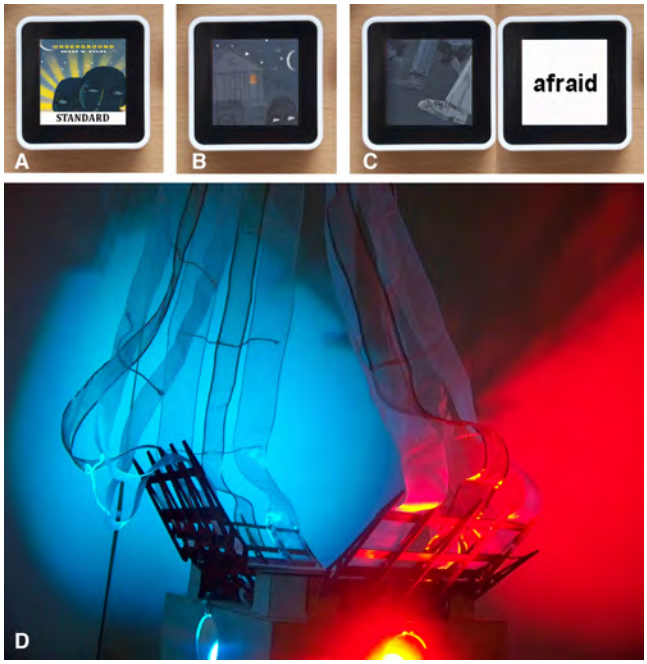

Figure 17. A: Standard menu option for "Underground." B: "Escape" image, pressed to activate color and movement. C: Word and image pairing to activate running sounds. D: LIT KIT full activation for "Escape."

When Sam chooses the image depicting "Escape" (Figure 17B) *the lights turn bright orange and red, and the paddles and streamers, set on "undulate," create a cluster of fast, chaotic movements representing a group of people moving together* (Figure 17D). *When Sam correctly pairs the image of running feet with the word "afraid"* (Figure 17C), *the sound of people running through a forest adds to the effect. Dad then continues reading the book, and the same process is repeated for the concepts of "Help" and "Freedom." After reading through the book once, Sam and Dad discuss its major themes, and decide to customize the environmental effects for each section using the "Set-Up" menu.*

Our research team created a video demonstration of the LIT KIT scenario to illustrate the refined design and all of its components in context [23].

6. FURTHER WORK AND CONCLUSION

By bringing picture-books to life, the LIT KIT and its associated room-scaled LIT ROOM being developed for deployment in a major public library, aim to scaffold dialogical reading and literacy development in a read-aloud setting. Having iteratively designed and produced a robust, functioning LIT KIT prototype, further development will focus on making the system more accessible to children, families and organizations by eliminating the need for a laptop computer. The current design requires a laptop to operate the system (functioning both as the communicative "middleman" between the Sifteo™ cube interface and the Arduino processor located in the base of the LIT KIT and as the speaker for the sound effects). However, the latest Sifteo™ "Intelligent Play" system [24], released in 2012, includes a small processing base that eliminates the need for a laptop during operation, and expands the number of cubes that can communicate with each other and the system to twelve cubes total. Therefore, the next iteration of the LIT KIT will aim to adapt to the new Sifteo™ platform, ultimately allowing the processing to be entirely self-sufficient. The Sifteo™ processing base also contains a small speaker; should that speaker not be sufficient to creating a desirable level of environmental sound-effects, the next iteration of the LIT KIT will include a speaker in its base.

Further investigations will test the usability of the LIT KIT system with children, parents and educators. Having piloted the "Smileyometer" questionnaire instrument with the research and design team, children will be asked to interact with the LIT KIT prototype to evaluate the system. In the Spring of 2013, the research team will present first grade children (ages 6-7) with the LIT KIT and ask them to deploy the system to recreate the ideas, concepts, actions and places represented in the picture-books. Using the questionnaire, as well as other established methods (observations, active interventions and talk-aloud protocols) [20], the research team will gather data on measures of usability, effectiveness and fun. The outcomes of the investigation will serve to further refine the LIT KIT, and will be presented in combination with the elaboration and findings presented here at the conference.

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