An Interactive, Cyber-Physical Read-Aloud Environment: Results and Lessons from an Evaluation Activity with Children and their Teachers

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ABSTRACT

As we come to live, work and play in an increasingly digital society, the future of interactive systems research, design, and practice will be shaped partly by larger-scale, cyber-physical systems. The cyber-physical LIT KIT enhances children's picturebook reading, both during and after interactive read-alouds, creating a multi-media, mixed-reality experience that transforms everyday environments into an environment evocative of the picturebook being read. The room-filled audio-visual-spatial effects of the LIT KIT contextualize language and provide feedback to the participants. The LIT KIT also acts as a story-extension tool, allowing children to customize environmental effects towards interpreting picturebooks *for themselves*. This paper offers a scenario of the child-computer interaction afforded by the LIT KIT, elucidates the motivations for its design, and focuses on an evaluation activity and its results. Particularly for DIS researchers in the educational domain, the LIT KIT represents a design exemplar that supports children's enjoyment of learning and meaning-making.

Author Keywords

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

ACM Classification Keywords

H.5.0 [Information Interfaces & Presentation]: General. I.2.9 [Artificial Intelligence]: Robotics. K.3.1 [Computers and Education]: Computer Uses in Education – *collaborative learning.*

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INTRODUCTION

Interactive read-alouds are contexts where children construct understanding in response to books. In this setting, knowledge is socially created through interactions between the text, the students and an adult reader, allowing children to respond spontaneously as they monitor their own comprehension within a community of learners [31]. Research indicates that these educational experiences can benefit children's development of important literacy skills, including vocabulary acquisition and comprehension [31, 33]. Moreover, when children are provided with opportunities to engage in embodied, visual-spatial activities before, during, and after reading, they are able to leverage mental imagery to construct meaning and make sense of the stories being read [6].

In such a conducive read-aloud environment, *words become worlds*. The LIT KIT [28] (Figure 1) aims to demonstrate that through engagement with a palate of environmental effects (lighting, sound and movement) at room scale, children's meaning-making can be cultivated within an engaging, mixed-technology environment that supports dialogical read-aloud interactions.

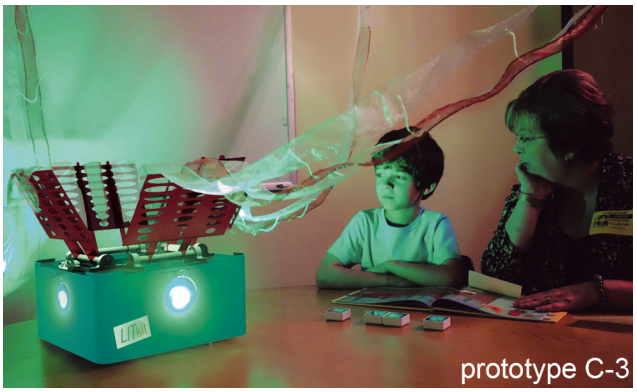

Figure 1. The LIT KIT (Prototype C-3), enhancing teacher-child interactions during picturebook read-alouds by transforming the physical environment with light, sound and movement.

READ-ALOUDS AND READER RESPONSE THEORY

In a read-aloud, an adult reads orally to children, in large group, small group or one-to-one settings, engaging them in conversations that support language and comprehension development. Fiction and non-fiction picturebooks are commonplace. A read-aloud experience that is both collaborative and situated in a physical environment conducive to learning encourages expressive and receptive language interactions [31]. Collaboration with children allows adult readers to adjust instruction to provide immediate scaffolding and feedback, usually by providing verbal prompts in the form of questions or comments [23]. Such dialogic interactions during the read-aloud align with Vygotsky's sociocultural theory of learning [36]. Further, within Rosenblatt's reader response theory, discussion is a critical factor in creating engaging educational environments favorable to children's meaning-making [26]. Her transactional theory, describing the fluid relationship between the reader (as interpreter) and the text, emphasizes the importance of a reader's aesthetic response to literature, where, through a "lived through" experience, the individual makes personal, sensory and emotional connections to the text as meaning is constructed [26]. During an interactive read-aloud, these connections are evidenced in a child's verbal responses to the text.

Research on children's response within the read-aloud context has begun to identify the types of meaning-making children exhibit when actively transacting with a text [6, 31]. Sipe argues that interactive read-aloud settings should be designed to facilitate a broad range of children's responses to the text [31]; and Baer suggests that novel technologies may hold promise in eliciting a more robust variety of meaning-making strategies [6]. The LIT KIT [28] aims to support both the socio-cultural and transactional theories of knowledge construction, leveraging technology in a novel setting to foster purposeful interactions between the text, children and an adult reader.

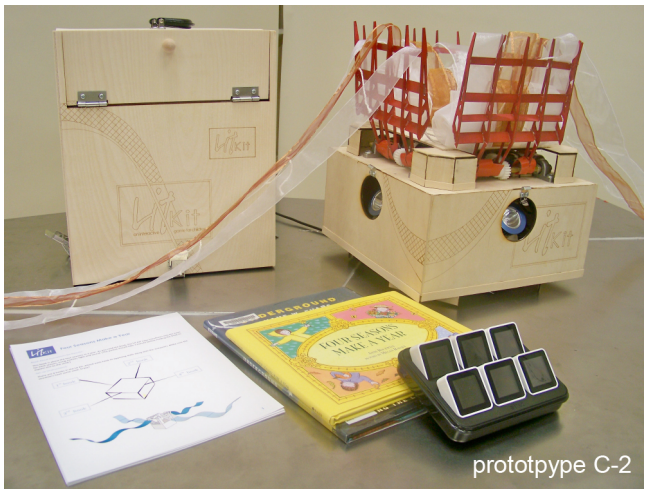

Figure 2. LIT KIT prototype C-2: its robotic paddles, streamers, lid, instruction pages, picturebooks and Sifteo™ interface.

THE LIT KIT SCENARIO

The following scenario describes how the LIT KIT system (Figure 2) transforms an interactive read-aloud into a multi-media, mixed reality experience in a child's bedroom. In this scenario, a child and her father interact with the system, which employs Sifteo™ cubes [32] to control the actions of the multi-media, architectural robotic [15] artifact. Here, the LIT KIT functions to provide environmental feedback to read-aloud prompts, contextualizes ideas from the picturebook being read, and serves as a tool for a child to make visible her thoughts and ideas. In this example, a child responds to *Underground* [13], a historical-fiction picturebook employing evocative images and language to chronicle the journey of slaves on the Underground Railroad:

Earlier today, Maya had an amazing story-time experience in an interactive space called the LIT ROOM [27] *at her public library. The accompanying LIT KIT was designed so that Maya could have a similar experience in the privacy of her home or in her classroom. Having checked-out one of the LIT KITs from the library that afternoon, Maya and her father – at home, in Maya's bedroom – read the instructions on the side of the LIT KIT. They open the drawer at the top of the LIT KIT and remove the picturebook entitled "Underground," which chronicles a group of American slaves and their journey from captivity to freedom. After removing the system instructions and the Sifteo™ cubes, father and daughter unlatch and remove the cover, placing the LIT KIT mechanism on a nearby table. Dad plugs-in the LIT KIT power cord and turns on the system with a button push. Dad also places the Sifteo™ cubes adjacent to the "Underground" picturebook next to Maya, and begins to read the instructions for the book:*

"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 that has a picture of the 'Underground' book cover and the word 'Standard.' Press this cube (see Figure 3A) *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."*

When Dad has finished explaining the overall concept of the book and the purpose of the LIT KIT, he and Maya set-up the system as illustrated in the instructions. Dad then begins reading the book aloud to Maya, guided by the instructions provided.

Dad and Maya get to the part of "Underground" where the characters begin their escape, when he is guided to prompt his daughter to look at the cubes and select the image that

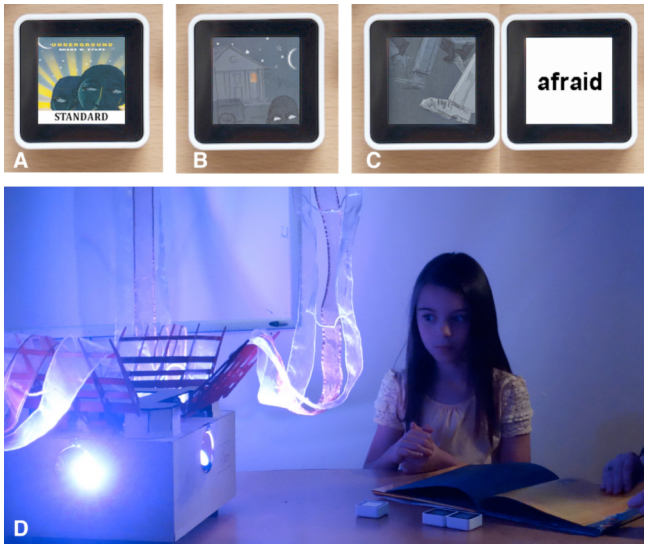

Figure 3. A: Standard menu option for *Underground* [13]. B: "Escape" image, pressed to reveal image/text prompt. C: Correct word / image pairing to activate "Escape" environmental effects. D: LIT KIT full activation for "Escape."

represents the concept of 'Escape.' The correct image directly correlates with the illustration in the book (see Figure 3B). *After Maya selects the correct image, the cubes change to depict one image from the book of running feet, and two words that express emotions. After reading on, Dad is guided to ask Maya to consider what it might feel like to be running away from something she was trying to escape. He prompts her to pair the image of running feet with the word that best expresses that feeling. At Dad's prompting, Maya correctly pairs the image of running feet with the word "afraid"* (see Figure 3C), *after which the system provides environmental feedback. The lights of LIT KIT alternate bright-blue and red, and the paddles and streamer undulate to create a cluster of fast, chaotic movements representing a group of people moving together* (see Figure 3D). *Additionally, Maya, upon hearing the sound of people running through a forest, adding to the overall effect, offers that "the shadows look like images of people running – the sounds make me think of times I've felt scared, too." Dad continues reading, repeating the same process for the concepts of 'Help' and 'Freedom.'*

After reading through the book once, Maya and Dad discuss its major themes, and decide to customize the environmental effects for each section using the 'Set-Up' menu. As Maya selects colors, sounds and movements for each section, her father asks her to explain her choices, providing an opportunity for her to leverage the LIT KIT environmental effects to create deeper meanings and connections to the story (A video demonstration of LIT KIT prototype C-2 can be accessed via the URL in [29].)

MOTIVATION FOR THE LIT KIT

Interactive read-alouds, for years a common instructional practice in elementary classrooms, are critical for building the knowledge required for eventual success in reading [3]. Over the last decade in the United States, read-alouds have been marginalized from the curriculum as focus has shifted to high-stakes testing and educational approaches that produce immediate, quantifiable results [37]. However, the recent, widespread adoption of the Common Core State Standards has renewed attention and interest in interactive read-alouds – in particular, those where texts are presented using diverse media and formats [21].

While research into technology-enhanced texts indicates the effectiveness of electronic and multimedia formats to children's literacy [9, 16, 17, 19], there is currently a gap when looking at the effects of diverse formats specifically in the read-aloud context. Nonetheless, the outcomes of these studies provide support for the hypothesis that digital/physical tools like the LIT KIT hold promise for enhancing dialogical interactions while reading picturebooks with children. For example, multiple studies comparing multimedia and electronic storybooks to static versions of the same texts suggest that the former can be more beneficial to young children's language development, their expressive vocabulary acquisition and story understanding [9]. Studies also indicate that interactive digital texts support children's social interaction and literary response, both critical components within interactive read-alouds [19]. Technology-enhanced texts promote new literacy practices that extend connections between children and the text, resulting in story understanding and personal meaning-making [17]. Additionally, since adult interaction with the child is so critical during the reading of picturebooks [31], augmented texts have been shown to create unique opportunities for parents and educators, through the use of prompts, to scaffold language, meaning-making and multimedia literacies [16].

Research into traditional read-alouds demonstrates that an interactive experience, where children engage with their peers and an adult reader, results in increased engagement with the text, and produces gains in both vocabulary acquisition and story comprehension [8]. Sadly, studies also show that not all parents and educators engage in instructive behaviors during a read-aloud that allow for discussion, feedback and the contextualization of the language in the picturebook [18, 22]. The LIT KIT was designed to provide multiple, unique opportunities for adult readers to engage with children, providing digital and environmental prompts to scaffold comprehension skills, at key moments in the texts and after the picturebook is read.

A common educational strategy for extending the meaning of the picturebook is to provide story-extension activities, such as writing, drawing, and dramatic play, allowing children to respond to the story and create new connections to the text [31]. Research indicates that interactive read-alouds can be more impactful when an adult reader layers in multiple opportunities for children to interact with a text in different modalities before, during, and after a picture-book is read [31]. Children who are encouraged to take

their understandings of a text and represent them through a different sign system (defined as *transmediation* [30]), are engaged in a process of building meaning, analyzing, and analogical/metaphorical thinking [1, 30]. While studies suggest that visual-spatial story-extension activities encourage transmediation, resulting in deeper thinking in the read-aloud context [6], there is a dearth of research into how tools employing diverse media may support children's meaning-making. The LIT KIT aims to fill this gap.

The LIT KIT also finds inspiration in the concept of embodied interaction [12], where "meaning is created through restructuring the spatial configuration of elements in the environment" [4]. Because the LIT KIT offers a picturebook 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" [4]. By transforming a home or classroom space into a robotics-embedded physical environment for children's meaning-making, the LIT KIT allows for "passage" between the everyday environment and the extraordinary environment imagined in books, providing unique opportunities for children and their adult guides to respond to the text.

Within the field of interaction design for children, a broad range of research focuses on technology-enhanced learning to promote children's literacy skills by engaging them with digital and multi-media elements [5, 35]. Related to the LIT KIT, researchers have developed augmented and mixed-reality books, both printed and electronic, that deploy different sensing, interacting and environmental technologies. The Listen Reader [5] was designed to create an immersive environment for a child reading a picturebook through high-quality embedded audio, triggered by sensing technology within the book. The Wonderbook [35], a large format augmented book, combines the physical book with sound and video projections that contextualize the text and provide opportunities for interaction between readers. Both studies concluded that large, multi-media augmented texts can encourage social and collaborative reading experiences, resulting in increased interest in the book being read. Although the Wonderbook participants recalled critical aspects of the story, and in particular, those contextualized through sound and video, the study is limited in terms of observing how readers might be leveraging the multi-media content for meaning-making.

Expanding beyond the physical pages of the book, other researchers have employed interactive tablets, tangible interfaces, responsive toys, robots, and augmented-reality viewing devices to deepen a book-reading and/or storytelling experience (e.g., [11, 20, 34]). While most of these studies focus primarily on the design and usability of the technologies employed, some of the outcomes suggest promise in digital and multi-media systems for providing feedback, fostering collaboration, and eliciting unique responses to the text. One example, the TinkRBook [11] explores the impact of interactive, multisensory features embedded within an electronic storytelling platform. Observations of parent/child interactions with the technology revealed that the enhancements increased engagement and encouraged dialogue about the story. Additionally, children in the study enjoyed exploring scenes in the story through multisensory interaction techniques. Another study employs a beloved children's character, Elmo, within a digital picturebook to serve as a conversational agent to scaffold concepts within the story being read [20]. Elmo interacts with the child as they read the picturebook, providing prompts and questions that create an interactive experience and contextualize the language. Preliminary tests indicated that while Elmo's feedback and scaffolding were effective, the best collaborative reading still occurred when an actual adult was present to guide the experience. SAGE [34], a digital/physical story-listening and authoring tool, combines an interactive plush toy to elicit unique storytelling strategies from children that are then digitally recorded. When compared to a truly digital interface, this tangible and embodied experience supported deeper explorations of identity and communcation, and provided opportunities for children to project fears, feelings and interests through stories. The LIT KIT aims to build upon the promise of these digital/physical literacy tools by expanding the multisensory feedback and prompting effects into the physical environment occupied by adults and children as they engage in shared picturebook reading.

Some studies have already explored the design and evaluation of "story rooms" that merge physical and virtual technologies at room-scale [2, 7, 10]. In these spaces, large-scale tangible props and multi-media effects are employed as prompts to encourage children to collaborate in the authorship of narrative stories. Both the KidsRoom [7] and the *Island of Sneetches* StoryRoom [2] guide children through a narrative story structure, leveraging the physical props and/or multi-media effects to elicit reactions and responses from the children. In these examples, as in the interactive StoryMat [10], a digital/physical mat that encourages children to create and record stories using small toys and projected images as prompts, participants leveraged the elements in the environment to make connections to stories and extend their meanings.

Whereas these state-of-the-art approaches to technology-enhanced literacy tools aim to create an engaging, immersive and interactive experience for children, the LIT KIT explores how a reconfigurable, multi-media, mixed-reality environment can support meaning-making strategies critical to an important literacy event: the interactive read-aloud. The following empirical study leverages the LIT KIT to ask these research questions: (1) Can children and adult readers comfortably use the technology during interactive read-alouds?, (2) How do the environmental effects aid users in the creation of meaning?, and (3) Can the LIT KIT's effects contextualize language, concepts and ideas in different types of picturebooks?

METHODS

An evaluation of prototype C-2 was carried out at a public elementary school (see Figures 4-6) over two days. Participants included teachers and students, ages 7-8 (one child in Classroom "B" was 11 years old), from two 2nd grade classrooms. The LIT KIT was evaluated during a whole-class (n=23 for Classroom "A," n=24 for Classroom "B") and a one-to-one read-aloud setting for each classroom (7 children per classroom; equal numbers of boys and girls). Two picturebooks with different characteristics were selected for the sessions. Relative to the research questions posed, the evaluative sessions were designed to elicit data on the system's *usability* (Question 1), effectiveness as a tool for *meaning-making* (Question 2), and its *applicability* across different types of picturebooks (Question 3).

Usability

To gather data on whether participants (adults and children) could comfortably use the LIT KIT during and after an interactive read-aloud, the research team was guided by established protocols for evaluating interactive technology for children (e.g. as per [24]). First, users interacted with the LIT KIT during a whole-class session, with the classroom teacher facilitating the read-aloud and administering the prompts for one of the two picturebooks. The research team observed the read-aloud, making notes on how the users engaged with the Sifteo™ cube [32] interface and reacted to the system. Immediately after the whole-class read-aloud, the teacher and the research team asked the children for feedback about their experience reading the book with the KIT. The session was audiotaped, videotaped and the discourse was subsequently transcribed. Additionally, the teacher completed a questionnaire that evaluated the LIT KIT on measures of usability and appropriateness for use in a read-aloud.

After the whole-class sessions, seven children, chosen by their teacher to represent a diversity of learner characteristics, participated in one-to-one sessions in a smaller, private reading room. For these sessions, the second picturebook was read aloud by a member of the research team with expertise in interactive read-alouds.

Figure 5. A participant responding to the environmental effects during a one-to-one read-aloud with the LIT KIT.

Participants were prompted to interact with the LIT KIT during the read-aloud (Figure 5), followed by a customization exercise where each child programmed the environmental effects for one specific concept from the book. The research team notated their observations, and the sessions were audiotaped, videotaped and observed for subsequent transcription of the discourse and verification of our notes.

Participants then completed a facilitated questionnaire (read to the children by the adult, who clarified questions as necessary) that rated the prototype on measures of usability, environmental impact, aesthetic design, and reading motivation and engagement. The evaluative questionnaire, utilized in the one-to-one sessions (see Figure 6), was designed specifically for children ages 6-8. The instrument employed was the "Smileyometer" [24], a graphic representation of the traditional "1-5" Likert scale with faces that illustrate varying levels of approval.

Representative questions included in the questionnaire were: *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?, 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?, How much did the LIT KIT feel like a game or a toy?, What did you think about the LIT KIT packaging?, What did you think about how the LIT KIT system looked when it was assembled?, How much did the LIT KIT help you to understand the book?, How much did the LIT KIT make reading the book fun?,* and *How much would you want to use the LIT KIT to read another book?* The questionnaire also employed open questions where participants provided verbal explanations, including: *Which of the LIT KIT's environmental effects did you like the most, and why*?, *What other types of things would you like to see the LIT KIT do?*, and *Do you have anything else you'd like to share with us about your LIT KIT experience today?* To offset any potential limitations of the "Smileyometer" instrument, such as the inclusion of leading or confusing questions, results of the questionnaire were confirmed against documented observations of usability errors exhibited by the children.

Figure 6. Administering the "Smileyometer" [24] questionnaire instrument after a LIT KIT read-aloud.

Meaning-Making

As picturebook read-alouds are discursive events where learners construct meaning together [31], one important method for understanding children's meaning-making, in that context, is to document and analyze children's response initiations (i.e. verbal talk) [31]. The whole-class and the one-to-one sessions were transcribed, noting instances where children seemed to be leveraging the LIT KIT's environmental effects to construct meaning related to the picturebooks. Furthermore, and guided by Baer's research [6] into children's response to texts using visuo-spatial (though neither digital nor environmental as in the LIT KIT) activities, the research team conducted an initial coding of the LIT KIT participants' verbal responses in order to suggest specific meaning-making strategies. Additionally, the questionnaire completed by the teachers after the whole-class read aloud asked them to rate the LIT KIT on its effectiveness as a tool to scaffold meaning-making.

Applicability Across Different Types of Picturebooks

In order to explore how the LIT KIT's effects contextualize language, concepts and ideas in different types of picturebooks, two texts were selected for the study. The narrative, nonfiction picturebook, *Four Seasons Make A Year* [25], teaches children about the changing seasons; and the historical fiction picturebook, *Underground* [13], chronicles the journey of slaves from captivity to freedom along the Underground Railroad. Children's responses were analyzed to suggest how the LIT KIT's environmental effects (light, movement, sound) might evoke not only the physical phenomena (trees, wind, rain, etc.) presented in *Four Seasons Make A Year* [25], but the emotions (fear, sadness, happiness, etc.) evoked by *Underground* [13]. The books were counterbalanced for the two classrooms. Classroom "A" read *Underground* [13] together in the whole-class setting, followed by *Four Seasons Make A Year* [25] in the one-to-one sessions, whereas Classroom "B" read the books in the opposite order. Additionally, the teacher questionnaire asked them to rate the system on its applicability to a variety of picturebooks.

RESULTS

Feedback from the participants in both read-aloud settings (i.e. whole-class and one-to-one) suggests that the system was easy to use, provided effective feedback to vocabulary and comprehension-based prompts, made reading the books fun and engaging, and created an environment that helped the children visualize concepts and think about the book. Additionally, the LIT KIT received a positive evaluation from children and teachers for use with both picturebooks.

LIT KIT Usability

The two participating teachers easily integrated the LIT KIT into their read-aloud session with minimal training on the system. Based upon the post read-aloud teacher survey, both participants indicated that: the system was easy to use; it was an appropriate and useful tool for elementary literacy education; it made the interactive read-aloud fun and engaging for students; and finally, that they would use the LIT KIT again in their classrooms.

During the whole-class read-aloud sessions (Figure 4), the teachers invited individual students to come to the table where the LIT KIT was located to interact directly with the Sifteo™ cubes [32]. The research team observed that some of the participants (more so in Classroom "A") exhibited difficulty when the desired action was to place two cubes together. Some participants in Classroom "A" pressed on both cubes, requiring corrective direction from the teacher. This was not an issue with the participants in Classroom "B," as the teacher provided more direct instruction prior to each child's interaction with the interface. Some participants in both classrooms had difficulty providing adequate pressure for the "press" action, resulting in multiple attempts for the same interaction. Additionally, the research team observed that some children did not readily understand the feedback provided by the cubes after making an incorrect selection.

For the one-to-one session, a post evaluation analysis of the questionnaire data suggests a positive rating from children for the LIT KIT on measures of usability, aesthetic design, environmental impact and reading motivation. Figure 7 shows the respective mean for each evaluative category, looking at comparative scores across books, with the means consistently higher with respect to the middle of the scale (represented by a score of 3) for each. The LIT KIT rated highest on the category of environmental impact, with nearly all children indicating the system was effective at transforming the environment in a way that was impactful and pleasing. High ratings on reading motivation suggests that the children surveyed would use the LIT KIT again for a read-aloud, and that the system may have helped them understand the book better through an engaging and fun experience. While ratings surpassed the middle of the scale for questions measuring usability, with 86% of the children indicating that the system was very easy to use, less than half (43%) of the children thought it would be easy to explain how to use the LIT KIT to a friend. This critical feedback may serve as evidence that many children in the study were not inclined to simply provide answers above the middle value and/or were uninfluenced by potentially leading questions in the instrument.

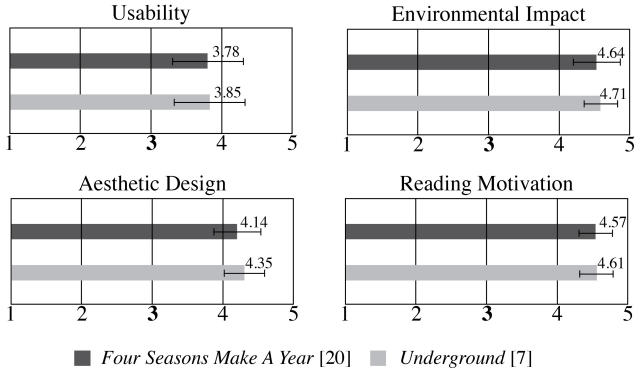

Figure 7. Questionnaire results per evaluative category.

Whereas most of the children in the one-to-one sessions successfully utilized the Sifteo™ cube [32] interface, an overwhelming majority of the children (79%) left the cubes on the table where they were initially placed during the session. Curiously, only three (3) of the children picked up the cubes while interacting with the LIT KIT, or moved the cubes to a different position on the table. Many children stood over the cubes for closer inspection as opposed to moving them closer to their own seat at the table. The research team also observed that the Sifteo™ cubes [32] competed for the visual attention of some of the participants during the read-aloud, as they visually attended to the interface at times when they should have been focusing on the book.

After the read-aloud, as described earlier, children in the one-to-one sessions were provided the opportunity to customize the environmental settings (lighting, sound and movement) in order to make visible their thoughts about one section in the picturebook (Figure 8). There was a lag-time of one to two seconds between a child pressing an option (such as the color blue), and the LIT KIT device displaying that change in effect (projecting the color blue). While children did not express direct frustration with the lag between the interface and the feedback, many times children would continue to press down on the cube, advancing the option without allowing the KIT to display the selection. The children's natural propensity to toggle through the options more rapidly than the KIT could tolerate indicated that the participants expected feedback to occur concurrently with selection.

Of the three LIT KIT effects – lighting, movement and sound – children identified the movement and lighting as being the most impactful in terms of contextualizing the language in the picturebooks. Additionally, many children requested a more robust palate of colors, movements and sounds for the custom setting.

Figure 8. A: Sample custom options for the "Spring" environment. B: A child programming lighting, sound and motion effects for "Spring" on prototype C-2.

The LIT KIT as a Tool for Meaning-Making

Both teachers indicated that the system was a useful tool for scaffolding meaning-making and vocabulary acquisition in the context of an interactive read-aloud. During both of the whole-class sessions, children spontaneously responded to the LIT KIT's environmental effects, and in many cases, related them directly to the book being read. A child in Classroom "A," experiencing the effects that contextualized the season of Fall, said: "Cool! That looks like leaves on a Fall tree!" Children in Classroom "B," during the reading of *Underground* [13], shared multiple interpretations of the kit's "Escape" effects. Looking at the lighting and shadows cast on walls and ceiling, one child commented: "They were walking hand in hand," while another said: "Those are footprints!" These responses indicate that children are able to consider both concrete objects (trees, seasons, and people) and emotions (such as fear) while immersed in the multi-sensory environment created by the LIT KIT. Additionally, the research team observed children spontaneously assisting and collaborating with each other to interpret and relate the environmental effects to the picturebook being read. In one instance, a child looked puzzled and voiced: "I don't get it", which prompted a neighboring child to help by pointing to the shadows and suggesting: "It was the people running. I can see that!"

Many children in the whole-class setting indicated that the LIT KIT was an effective tool for helping them visualize the books being read. After the read-aloud, the research team asked the open-ended question: *Do you have any comments about the KIT that you would like to share?* One child stated: "I think [the LIT KIT] was really cool and fun, and I actually think it would help with the pictures (from the book), because sometimes when a teacher's reading to me, I want to be able to see the pictures in my head and [the LIT KIT] really helps." Many comments supported the capacity of the sound effects, in particular, to help the children understand what was happening in the books. Other children commented positively on the feedback component of the system, describing the Sifteo™ cube [32] prompts as both "fun" and "challenging."

An initial analysis of the children's verbal response initiations, both in whole-class and individual picturebook read-alouds, revealed many instances where the LIT KIT supported meaning-making processes. Children were able to leverage the palate of environmental effects to make visible their imaginings and ideas. The lighting, movement and sound, rather than distracting children from key constructs in the texts, formed an effective tool palate for elaborating meaning. Moreover, children were able to verbally articulate the reasoning behind their choices, suggesting that the multi-media, mixed-reality elements helped them to explain *how* they constructed meaning.

Overall, the LIT KIT elicited a wide range of response initiations from the participants in the study. Some children constructed meaning by using the multi-media effects to help them make sense of the picturebook being read (Table

1, A), while others used them to make connections between the text and their own life experiences (B). Students also created meaning by articulating the feelings or physical sensations depicted in the picturebook (C), while others utilized the environmental effects to elaborate on the story (D).

A	*Children make sense of the text:*	
	Comparing how the LIT KIT changed from "Spring" to "Fall" for *Four Seasons* [25], one participant said:	"The light and motion are changing because the leaves used to be green and now they changed to orange. And the breeze is calmer in Summer than in Fall."
B	*Children make connections between the text and their own life experiences:*	
	In response to the LIT KIT spatializing the "Fall" season in *Four Seasons* [25], one participant said:	"The light and shadows make me think of when it is Fall: me and my brother, we'd be making a big pile of leaves and be jumping in it. And then the leaves go everywhere."
C	*Children show empathy by understanding feelings or physical sensations depicted in the text:*	
	In response to the LIT KIT evoking the concept of "Freedom" in *Underground* [13], one participant said:	"It makes me feel good and happy because I play basketball and it looks and sounds like people cheering and like congratulating people for being free."
D	*Children elaborate on the text:*	
	While explaining her rationale for selecting the *twist* motion setting to represent the concept of "Escape" in *Underground* [13], one participant said:	"When wind twists, it makes a tornado which is scary like this."

Table 1. Initial categories of LIT KIT response initiations, with examples from children participants.

Applicability of the LIT KIT Across Picturebook Types

Both teachers indicated that the LIT KIT could be adapted to a variety of picturebooks. Relative to the two books used in the study, children utilized the multi-media effects to represent the physical phenomena (trees, wind, rain, etc.) and actions (swimming, eating, flying, etc.) evoked by the *Four Seasons Make A Year* [25] picturebook. For *Underground* [13], children successfully transformed the environment to depict the feelings of the characters (fear, sadness, happiness, etc.), and abstract concepts (such as slavery and freedom).

After children explored the custom settings, the adult-reader had a dialogue with the children to discern their rationale (Figures 9 and 10). To contextualize the concept of "Spring" from the book *Four Seasons Make a Year* [25], children chose a variety of lighting, and discussed their reasoning (*green* to represent leaves; *blue* to represent rain, and *red* to represent apples and flowers), sounds (*wind and rain; eating an apple* to represent an apple tree, and *running* because when it rains people run to avoid getting wet), and movements (*fall* to represent the motion of rain; *rotate* and *sway* to represent the motion of wind in the trees; *undulate* to represent the motion of someone swimming, and *soar* to represent the motion of a bird's wings in the air). In many of these cases, children were constructing ideas about "Spring" that went beyond what was represented in the picturebooks, making connections to other texts and background knowledge.

Figure 9. A participant explains his rationale for choosing the color *red*, the *sway* motion, and *eating an apple* sounds to represent the concept of "Spring" in *Four Seasons* [25].

The LIT KIT was equally effective at contextualizing an abstract concept such as "Escape," or the emotional qualities evoked by the *Underground* [13] (see Figure 10). Children chose a variety of lighting colors (*red* to represent anger, fear and nervousness; *blue* representing the color of night and the emotion of sadness), sounds (*wind*, *running* and *night*, each directly related to the context in the book), and movements (*shake* to represent the motion of the slaves shaking with fear; *sway* to represent the ominous sounds of night that evoke fear; *twist* for the slaves stumbling over each other as they ran). Many children utilized the multi-media effects to extend the meaning in the book, thinking both analogically and metaphorically, which may represent high-order comprehension.

Figure 10. A participant explains her rationale for choosing the color *red*, *shake* motion, and *running* sounds to represent the concept of "Escape" in *Underground* [13].

DISCUSSION

The LIT KIT aims to scaffold dialogical reading interactions in a read-aloud setting, and leverages multi-media effects to provide feedback, prompt children's response to the text, and create a unique environment for them to think about different types of picturebooks. Findings from the LIT KIT evaluation suggest that the system proved easy-to-use by teachers and children, and that the participants believed that an interactive read-aloud with multi-media enhancements facilitated their understandings and was both engaging and fun. Moreover, the LIT KIT created unique opportunities during and after the interactive read-aloud for adult readers to fulfill their roles as guide, facilitator, questioner and responder, an important factor for children's meaning-making [31].

One theory of children's meaning-making (as evidenced by their verbal response) suggests that, when connections are made to a picturebook through visual-spatial activities, children utilize mental imagery to mediate between an idea about the text and an understanding of the world-at-large [14]. A child first makes an abstract mental image of some concept about the picturebook, translates it into a concrete, spatial representation (in this case, through environmental effects); and then, through discussion, makes connections between the idea, its representation, and the world [14]. Through this theoretical lens, the LIT KIT may serve as a child's conduit between the everyday environment and the extraordinary environment imagined in picturebooks.

CURRENT AND FUTURE WORK

Drawing on the outcomes of our field study, the research team fabricated a more refined iteration ("C-3") of the LIT KIT (Figure 1) from lightweight steel, adding a more robust palate of colors and sounds. Further evaluation activities with children will study the performance of C-3, alone and in comparison to traditional read-alouds, including more in-depth analysis of meaning-making strategies exhibited.

LESSONS LEARNED

This research yields important lessons as our communities – Design, Computing, and Education – develop cyber-physical artifacts supporting everyday learning activities.

Firstly: Design teams developing cyber-physical learning tools must ensure that evaluations of the artifact occur within its most challenging, targeted environment: a public elementary school classroom during an interactive read-aloud in the case of the LIT KIT.

Secondly: Designing and developing technology for classroom applications should accommodate user customization, affording unexpected interactions with young users and their teachers that, in all likelihood, exhibit different needs, interests and capabilities.

Thirdly: When seeking to provide technological responses to complex challenges, like early learning, design team members who are newer to processes of user-centered design methods need to ensure that cyber-physical tools adequately address basic needs (e.g. size, weight, and issues concerning safety), aesthetic qualities (e.g. color, form, movement), and user experiences, towards promising children and their teachers an engaged, productive and fun interaction with minimal complications.

More broadly, for the larger DIS community, the LIT KIT is a case of *research through design* that strives to improve the world we live in. As cyber-physical artifacts like the LIT KIT become ubiquitous, they should be made attractive, intuitive, reflective of human users with wide-ranging capabilities and interests, and adaptable as vehicles for human-computer interaction.

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