# Exploring the Design Space of Tangible Systems Supported for Early Reading Acquisition in Children with Dyslexia

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**ABSTRACT**
Tangible user interfaces have the potential to support children in learning to read. This research explores the design space of school-based tangible learning systems that support early reading acquisition in children, particularly in children with reading difficulties. Informed by theories of the causes and interventions for dyslexia and research on TUIs for learning, we present the design of a tangible reading system that uses the dynamic colour and tactile cues to help children with dyslexia to learn English letter-sound correspondences. We then propose a case study design that investigates how this system can support children with dyslexia aged 7-8 years old in learning letter-sound correspondences in a school context. We conclude by discussing the future work and potential contributions of this research.

**Author Keywords**
Tangible User Interface; Reading; Children with Dyslexia.

**ACM Classification Keywords**
H.5.2. [Information interfaces and presentation]: User Interfaces. K.3.1 [Computers and Education]: Computer Uses in Education-*Computer-assisted instruction*.

## INTRODUCTION
Reading ability is one of the core competencies that affect the achievement of many other essential abilities in people. Learning to read is a cognitive process in which learners need to pass through each stage (i.e., from partial to full letter-sound correspondences, and to comprehension) to gradually develop accurate and fluent reading abilities [4]. However, approximately 10% of children in English-speaking countries experience difficulties in learning to read. This specific reading impairment is commonly referred to as "dyslexia" [12]. The most direct cause of dyslexia is suggested to be poor phonological awareness, i.e., the ability to manipulate sounds in speech [4,12]. Specifically, phonological deficits impede dyslexic children's ability to manipulate sounds, which leads to their difficulties in acquiring the early reading knowledge of letter-sound correspondences [15]. Although traditional multisensory intervention has shown its efficacy in helping children with dyslexia to learn to read, this approach is extremely labor-intensive due to its intensive, prolonged, and one-to-one training process [9].

Tangible user interfaces (TUIs) have the potential to support learning to read for children. These claims are based on the unique characteristics of TUIs such as their spatial nature [13] and the inclusion of multiple modalities of representations [1], both of which may benefit the early reading acquisition stage in children, particularly in children with dyslexia. While many tangible reading systems have been developed for children, only a few have targeted the early reading instruction of letter-sound correspondences [5,6,14], and even fewer have been designed for children with dyslexia (see excepts of [10,11]).

The goal of this research is to explore the design space of tangible learning systems that support early reading acquisition for children, especially for those with dyslexia. This work is informed by theories of the causes and interventions for dyslexia and research on TUIs for learning. Based on the implications of theories and previous research, we present a set of design considerations for designing tangible reading systems that support early reading acquisitions for children with dyslexia, and the specific prototype design based on these considerations. We also propose a case study design to investigate how this system can support early reading acquisition for 7-8 year old children with dyslexia in a school context. Future directions will focus on conducting the study and analyzing the results, refining the design of colour-coding schemes for each learning activity, and improving the interaction and UI design of the system in general.

## BACKGROUND
### Theories of the Causes and interventions for Dyslexia
Although dyslexia is heterogeneous, the most direct cause is suggested to be the phonological deficit in manipulating


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sounds in speech [4,12]. Poor phonological awareness increases the difficulties for dyslexic readers in associating speech sounds with printed letters when learning to read [15]. Therefore, unlike typical readers who can learn letter-sound rules **implicitly**, dyslexic children cannot learn to read unless the letter-sound rules are **explicit**. In addition, learning to read English poses particular challenges because the language contains many multi-letter (e.g., 'ough'), morphemic (e.g., 'tion'), and inconsistent letter-sound correspondences (e.g., 'ea'/e//i:/) that English contains[4].

Traditional multisensory reading interventions have shown efficacy in supporting children with dyslexia [9,12]. This approach focuses on explicit and intensive trainings on letter-sound correspondences by using the multisensory method wherein visual, auditory, tactile, and kinaesthetic senses are simultaneously linked to explicate the letter-sound relations [9]. The Orton-Gillingham (O-G) program is one example of such multisensory instruction. In O-G, physical letter tiles are often used to attract children's attention to the letters and sounds [9]. The physical letters also allow for letter tracing activities which can help dyslexic children to better recognize mirrored letter shapes and memorize letter-sound correspondences [2]. In addition, tutors also use colour cues to highlight the grouped phonemes/digraphs/syllables (e.g., house, eat) [3] or stable patterns (e.g., pat, rat) [8] within words. However, one limitation of this approach is that it is resource intensive so it is not widely available to children.

### Research on TUIs Designed for Learning to Read

TUIs have the potential to support learning to read for children. First, research has suggested that TUIs may have particular benefits for learning domains that involve spatial properties, either physically or metaphorically[13]. Letters are visual symbols represented in 2D space. To understand a sentence, children have to decipher a series of letters in a certain spatial order to have it make sense. The spatial quality of TUIs can support children in constructing letter sequences through hands-on actions in space. Second, TUIs incorporate multiple modalities [1], which may particularly benefit the learning for children with dyslexia. The simultaneously linked modalities can explicitly illustrate the letter (visual) - sound (auditory) relations. The tactile modality can provide a wide range of learning activities such as letter tracing and manipulation. These hands-on actions help to attract children's attention to the letters and letter-sound correspondences. The tactile modality can also provide physical affordances so children can easily learn how to use the system [13].

Although TUIs may have the potential to support early reading acquisition for children, particularly children with dyslexia, there are few tangible systems that were designed to support the learning of letter-sound correspondences. Sluis and colleagues presented Read-It, a tangible tabletop designed to support collaborative learning of phonological awareness of children who speak Dutch [14]. In Read-It, children have to match the card (word) with other cards (words) that start with the same sound. The strength of the design lies in its central focus on phonological training. However, this prototype only focuses on the training of onsets. Although learning onsets helps children learn language like Dutch, which has transparent (consistent) letter-sound mappings, this design does not support the learning of opaque (inconsistent) letter-sound rules such as those English has. Two cube-based tangible prototypes, Spelling Bee [5] and Spelling Cube [6], were also developed to support the learning of letter-sound correspondences. In both systems, each facet of the cube represents a letter. A learner needs to rotate each cube to select the correct facet and then connect cubes together to make a word or sentence. However, both systems use generic blocks to represent letters so they do not support children in explicitly connecting the sounds of letters to their visual forms (through letter tracing activities).

While few tangible prototypes target letter-sound correspondences, even fewer have been found that are specifically designed for children with reading difficulties. We only found two systems that were designed for dyslexic children and one that was designed for pre-linguistic toddlers. SpellBound is a tangible system that supports children with dyslexia in learning letter-sound correspondences. SpellBound allows children to construct 2D letters by using a set of wooden shapes that contain visual features of letters (such as the crossbar of a t or tail of a q). Children can then place the 2D letters onto a platform to trigger the letter's sound and a picture of the word that the letters spell out [10]. However, the researchers only sketched the initial idea; this prototype has yet to be fully developed. Tiblo uses Lego-like blocks to represent any of several different concepts, including words, numbers, and potential phonemes [11]. Children with dyslexia can draw the concept on a piece of paper, attach it to a block, and record the sound for the concept. A set of blocks finally can be connected in a certain order to represent a word, narrative or any other concepts. In other words, Tiblo is not dedicated to the acquisition of letter-sound correspondences. As with Spelling Bee and Spelling Cube, the generic forms of the blocks do not explicitly support children in linking letter sounds and visual forms. Hengeveld and colleagues developed the LinguaBytes, a tangible system aimed at stimulating the language development of pre-linguistic speaking Dutch toddlers [7]. Since toddlers have not started to learn letter-sound mappings, the majority of the exercises in LinguaBytes aim to encourage toddlers to communicate through story reading. Although LinguaBytes incorporates letter-sound activities, they only allowed children to learn the simple one-to-one letter-sound associations, and may not help children to learn inconsistent letter-sound mappings.

## THE DESIGN SPACE OF TANGIBLE SYSTEMS SUPPORTED FOR EARLY READING ACQUISITION FOR CHILDREN WITH DYSLEXIA

Based upon the theories of the causes and interventions for dyslexia and previous research on TUIs, we present a set of design considerations for designing tangible learning systems that support the learning of letter-sound correspondences for children, particularly for children with dyslexia. We then present the design of PhonoBlocks, a tangible reading system that uses dynamic colour cue and tactile cue to help children to learn letter-sound correspondences of English.

### Design Considerations

- The phonological deficit of dyslexia suggests that the learning goal should focus on letter-sound correspondences rather than vocabularies or narratives.
- The opaque orthographies of English suggest that the learning activities should incorporate complex letter-sound rules within word contexts.
- The multisensory interventions suggest the potential of using the colour cue and tactile (letter-tracing and manipulation) cues to promote the learning of letter-sound correspondences.
- The importance of letter-tracing activities suggests the inclusion of letterforms in the design of physical representations in TUIs.

### The Design of PhonoBlocks

PhonoBlocks is a tangible reading system designed to help 7-8 year-old children with dyslexia to learn English letter-sound correspondences through a set of word building activities. This system consists of a digital display, a platform with seven slots and 44 lower-case plastic letters. Children learn to read by placing the 3D letters onto the platform. Visual-audio feedback is provided at the display including 2D letters, letter sounds, and associated pictures. Meanwhile, colour feedback is also provided within the 3D letters through the changes of LED strips (Figure 1).

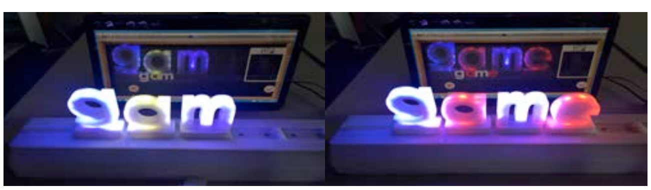


**Figure 1. PhonoBlocks: In the Magic e activity, the colour of letter a changes from yellow to red to illustrate the vowel sound change (i.e., short -> long).**

PhonoBlocks contains five sub-learning activities and supports two modes for each learning activity. The tutor's mode enables the tutor to direct the learning while the student's mode allows for practice-based learning by the child alone. PhonoBlocks uses dynamic colour cues and 3D tangible letters to promote the learning of letter-sound correspondences. Compared to the non-dynamic colour cue in traditional interventions[3,8], here the dynamic colour cue can better attract children's attention through the colour changes (e.g., from colour-off to on). Furthermore, the dynamic colour cue is also advantageous in **explicitly** highlighting various letter-sound relations of English in word contexts (e.g., gam->game). Given the various rules of English, we designed different colour-coding schemes to best illustrate each rule (see Figure 1). The 3D tangible letters here enable the children to easily trace and manipulate letters in space by hands. The physical constraints embedded with tangible letters leverage the use of physical laws and can be easily learnt by children.

## RESEARCH QUESTIONS

In order to explore the design of PhonoBlocks, we ask the following primary research questions. (1) How do children with dyslexia learn to read and spell in instruction with PhonoBlocks? (2) How do children with dyslexia learn differently between PhonoBlocks instruction and the O-G instruction? (3) How do tutors' teaching styles differ between PhonoBlocks instruction and the O-G instruction? (4) How do individual children's personal characteristics and tutors' teaching techniques influence the children's responses to PhonoBlocks instruction? (5) What strengths and weakness of PhonoBlocks do tutors and children perceive in supporting learning to read and spell?

## RESEARCH DESIGN

We designed an exploratory study involving around twenty 7-8 years old children at-risk for dyslexia learning letter-sound correspondences either under PhonoBlocks instruction or under the school-based O-G approach at the Kenneth Gordon Maplewood School (KGMS), a learning center that specializes in language instruction for children at-risk for reading difficulties in Vancouver, Canada. There are two main reasons for a case study approach. First, it is important to investigate the design of PhonoBlocks in a natural classroom context. The case study here enables us to explore the promise of PhonoBlocks of a classroom tool by evaluating the dynamic relations between the child, tutor and computer-supported technology. Second, case study allows for a deep exploration by collecting various data sources such as children's reading scores, children's learning behaviours and tutors' opinions and so forth.

The research design will contain an analysis of individual cases with ten children at-risk for dyslexia who will receive 12 training sessions of letter-sound correspondences with PhonoBlocks. Here we also include an additional group of ten children at-risk for dyslexia who receive the traditional O-G instruction. Both instructions are part of the children's scheduled sessions of special education in the KGMS. We added the O-G group for two reasons. First, although our goal is not to make claims about PhonoBlocks efficacy, we wished to supplement our qualitative analysis with a quantitative description of the magnitude of changes in performance. Second, the O-G group provided us a baseline for assessing the degree of individual variance in children's performance and which behavioural factors influence performance, both of which could be relevant to how children react to PhonoBlocks. The O-G group can also help to identify differences in the behaviours of children using and not using PhonoBlocks. Before, during and after the study, the children in both groups will receive a set of reading and spelling assessments. We will collect and analyze the scores to examine each child's learning trajectories (RQ1). We will also videotape and take observational notes about the children's learning performances and tutors' training processes between the two groups (RQ2, RQ3 & RQ4). The children using PhonoBlocks will be given questionnaires involving likert-scale questions pertaining to the system and some demographic information (RQ4&RQ5) while tutors will be interviewed about their opinions of the system (RQ5).

## CONCLUSION AND FUTURE WORK

We presented a set of design considerations informed by the theories and previous work, and proposed the design of a tangible reading system called PhonoBlocks that uses dynamic colour and tactile cues to support the early reading acquisition in children with dyslexia. Our future work includes conducting the study and analyzing the data. Based on results of the first study, we may further refine our design and conduct a second larger-scaled study. The potential contributions of this work are the specific PhonoBlocks prototype, our specification of the core design features that support learning to read and our specification of the considerations that can guide the design of tangible learning systems involving reading tasks for children, particular those with dyslexia.

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