Designing Colours and Materials in Tangible Reading Products for Foreign Language Learners of English

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CHI'18 Extended Abstracts, April 21–26, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3188577

Abstract
One design challenge of tangible reading systems is how to leverage the design of physical properties to best support the learning process. In this paper, we present an exploratory study which investigated how 18 young adults who learn English as a foreign language associated colours and materials to English letter-sound pairs. The preliminary results indicate that the letter-sound-colour mappings are influenced mainly by the literacy meaning of the letters while the letter-sound-material mappings are strongly affected by the characteristics of letter sounds. We discuss the design implications and future work for designing tangible reading systems for foreign language learners.

Author Keywords
Tangible user interfaces; colours; materials; reading; English foreign language learners; design implications.

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g. HCI): User Interfaces—Theory and methods.

Introduction
Learning letter-sound pairs plays a vital role in the subsequent reading development in children [4]. Recent research has suggested the potential of tangible

	Materials		Materials
1	Glass	13	Plastic bag
2	Metal foil paper	14	Silk
3	Plastic grid	15	Raincoat cloth
4	Net	16	Linen
5	Leather	17	Velvet
6	Foam	18	Textured (dot) rubber
7	Frosted glass	19	Slick paper
8	Felt	20	Sandpaper
9	Towel	21	Tissue
10	Styro-foam	22	Rubber
11	Paper	23	Feather
12	Cotton	24	Fur

Table 1: Twenty-four types of white-hued common materials.

user interfaces (TUIs) in supporting learning letter-sound pairs for children, particularly for children with poor Phonological Awareness (PA: the ability to manipulate sounds in speech) such as those who learn English as a foreign language (EFL) [1]. In this regard, several child-centric tangible reading products have been developed for both commercial (e.g. Osmo [9]) and research purposes [2,8]. Despite the differences, these tangible products all include the physical representations of letter symbols, the digital objects of letter sounds, and the design element of colours in both digital and physical sides. Although tangible reading products have repeatedly used the design elements including colours and materials, their design decisions have been based largely on aesthetic considerations rather than theories of the role of multi-modal representations in reading acquisition or empirically validated guidelines. To our knowledge, little research has been done to explore how to leverage colour and material properties to support learning to read, especially how EFLs perceive the colours and materials in their reading acquisition. To design these elements effectively we need to know if there is a consistent relationship between letter-sound pairs and colours and materials.

In order to address this gap, we present an explortory study that investigated how young EFLs associated colours and materials to English letter-sound pairs. We focus on young EFL adults because (1) the rise of English as an international language results in an increasingly growing EFL population; and (2) previous studies suggested letter-sound-colour mappings may be influenced by previous language learning, so working with adults to understand their associations can then be transferred to design for children [7]. Our research questions are, ***RQ1*** *Are there any consistent letter-sound-colour/material mappings among young EFLs?* ***RQ2*** *What are the underlying reasons for such mappings?* and ***RQ3*** *Does their first language influence the mappings?* Addressing these questions will provide guidance for designers looking for justifications for their decisions of colours and materials in the design of tangible reading products.

Backgrounds

Colour and material design in TUI reading products

Shadow Box is a tangible tabletop that supports children in associating a word with its sound and meaning [8]. The wooden blocks were chosen because the potential users of this prototype — children — are familiar with such a material. Although each wooden block was painted with a unique colour, the use of various colours seemed only for making the product aesthetically appealing. Other non-learning related designs have been used in a recently released commercial product called Osmo. Osmo allows children to use a set of wooden letter cards to interact with games on an iPad. The designers intentionally used the colour cues (red and blue) to divide the letter pieces into two groups to allow two learners to join the activity together. However, this colour design was made based on the consideration of collaboration rather than learning. PhonoBlocks is the first tangible reading system that leverages the uses of embedded dynamic colour cues within 3D tangible letters to support children learning the alphabetic principle [2]. The authors mentioned that some of their design choices were made based on the results of focus groups with teachers (e.g. blue for consonants and red for vowels). However, they also acknowledged the design challenges for associating colours to letter-sound pairs

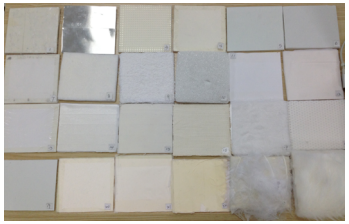

Figure 1: Twenty-four pieces of materials wrapped on square objects.

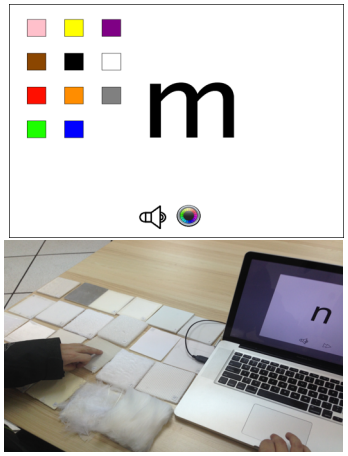

Figure 2: Interface for the colour study (*up*); Interface and materials for the material study (*down*). We used Century Gothic font recommended by the teachers working closely with children.

and advocated that other researchers continue exploring this field [1].

Cross-modal mapping research

Researchers have explored grapheme (letter)-colour synaesthesia to understand how people associate letter symbols with colours. Synaesthesia is when people experience cross-modal associations, particularly between letter symbols and colours [6]. For example, synaesthetes "see" the sound *a* as red. Researchers agree that such mappings are not arbitrary, and that such mappings could be influenced or changed by literacy learned later in life [7]. For example, *a* is for apple, and apples are canonically red, so *a* is mapped to red. In terms of materials, we have not seen any research exploring how letter-sound pairs are associated with material properties. However, in educational programs, practitioners often use the Object-Imaging-Projection method to teach children letter-sound pairs [3]. In this method, letters are associated with particular objects that have forms very similar to the letter shapes and that have beginning sounds that are the letter sounds. For example, *o/o/* is often associated with *orange*. This approach shows that people can associate letters with materials. Although researchers have investigated associations involving letter-sound pairs and colours, their investigations focused on synaesthesia. We have not seen any research that investigates how typical learners, particularly EFLs, associate letter-sound pairs with colours and materials, and how designers could use these findings to inform designs.

Methodology

We used a mixed method study design based on previous studies in synaesthesia. The study design for letter-sound-material mappings was also informed by "material probes" which explores the conceptual dimension of materiality in interaction design [5]. We drew on this methodology because it allowed us to understand how readers perceived material qualities of objects when making mappings.

The participants consisted of 18 Chinese college students (9 males and 9 females) with an average age of 20 years old. As an exploratory study, we included a small number of participants because we wanted to know not only whether or not there are consistent associations but also the underlying reasons for them. The participants reported that they had passed the Chinese Official College English Text Band Six which meant that they had acquired a moderate-level knowledge of English. Participants were tested before the experiment to ensure they did not have any visual, auditory or tactile deficits or synaesthetic experiences.

Research materials

The colour stimuli were eight letter-sound pairs, including *b/b/*, *d/d/*, *p/p/*, *g/g/*, *m/m/*, *r/r/*, *t/t/*, *n/n/*. The material stimuli were 12 English letter-sound pairs which contain the previous eight pairs used in the colour study and four additional pairs including *f/f/* and *v/v/*, as well as *a/a/*. The stimuli included both letters with mirrored shapes (e.g. *b*, *d*, and *p*) and with similar pronunciations (e.g. */m/*&*/n/*, */f/*&*/v/*) which involved letter-sound pairs with strong literacy bias (literacy bias means that a pair has strong metaphoric mapping for certain objects that are canonically associated with a certain colour or material, e.g. *a*-apple-red) or a pair has a strong associated word in literacy (*g*-green). We used 11 irreducible colours used in previous studies: black, white, red, green, brown, grey, yellow, pink,

Letter Sound (L-S)	Top 1	Top 2
b/b/	Blue: 36.1%	White: 13.9%
d/d/	Black 22.2%	Brown: 22.2%
g/g/	Green: 30.6%	White: 19.4%
m/m/	Pink: 25.0%	Orange: 16.7%
n/n/	Pink: 22.2%	Brown: 16.7%
p/p/	Purple: 22.2%	White: 22.2%
r/r/	Red: 25.0%	Yellow: 16.7%
t/t/	Green: 22.2%	Grey: 16.7%

Table 2: The two highest percentages of the letter-sound-colour mappings for each pair.

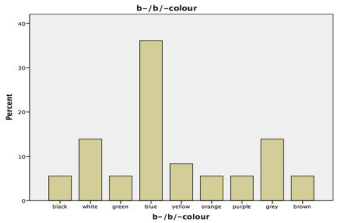

Figure 3: Frequency distributions of colours for the b/b/ pair.

orange, blue, and purple [6]. We included 24 types of white-hued common materials, selected based on the considerations of metaphoric mappings between letters and objects and a wide range of roughness [3,5] (Figure 1). We treated the material as a whole subject and focused on most of its properties (textures, weights but not colours) (Table 1).

Procedure

The colour study was conducted first. Participants were instructed to see a letter, listen to its sound, and then choose one colour from a palette of 11 colours (Figure 2). They were allowed to choose the same colours for multiple letters/sounds. Before the experiment, the participants were given a few trials. The session was self-paced, and participants could play the given sound as many times as they wanted. The trials were repeated two times to check the consistency of participants' choices. A post-interview was conducted after the tasks. Participants were asked a list of open-ended questions about what factors influenced their selection. For example, participants were asked why they chose a certain colour and which (the letter symbol or sound) was the dominant factor for their selections. The material study was conducted a week later to avoid interference from the colour study. The participants were provided with a set of 24 types of common materials. The procedure was similar to that of the colour study.

Data collection and analysis

System logs were used to record participants' selections for letter-sound-colour mappings. Observational sheets were used to record their letter-sound-material mappings. The post-session interviews were used to collect participants' reasons for choices.

To address our *RQ1*, we used a quantitative analysis method to determine the consistency of the mappings. We first conducted a descriptive analysis of the frequency distributions of participants' colour or material choices for each pair. In order to analyze our results we then calculated an estimate of the probability that a given letter-sound-colour/material mapping could occur by chance, informed by previous research [6]. Specifically, we re-coded participants' two-trail responses to one by assigning (black-0, white-1…, brown-10) and their consistent material responses to the values of 0-23. We then calculated the percentage of a certain letter-sound colour and used it as the baseline for calculating binomial probabilities. For example, the colour blue took up 14.3% of the total number of participants' consistent choices, so the probability that a given letter-sound pair should be assigned to colour blue (all things being equal) was 0.143. If eight out of 18 made consistent colour mappings for the pair *b/b/*, and six of these were blue, given the overall probability of choosing blue (0.143), this result was highly significant ($p<0.001$). To answer *RQ2&3*, qualitative thematic analysis was used to analyze participants' justifications

Preliminary Results

Consistent letter-sound-colour/material mappings

We first calculated the colour frequency distributions of two trials for each letter-sound pair. For example, Figure 3 shows that the letter-sound pair *b/b/* elicited the colour blue above all others. We then calculated an estimate of the probability that a letter-sound-colour mapping could occur by chance. Among all the consistent mappings, extremely significant results were found between *r/r/* and red ($p<0.001$) and *b/b/* and blue ($p<0.001$), followed by significant results of

L-S	Top 1	Top 2
b/b/	Plastic grid (PG): 19.4.%	Metal foil paper(MFP): 19.4%
d/d/	PG: 19.4%	MFP: 13.9%
g/g/	Linen:16.7%	MFP: 16.7%
m/m/	Fur: 30.6%	Velvet: 25.0%
n/n/	Velvet:19.4%	Cotton:13.9%
p/p/	Styro-foam: 25.0%	PG: 16.7%
r/r/	Linen: 16.7%	Velvet: 13.9%
t/t/	MFP: 27.8%	Styro-foam: 13.9%
f/f/	Feather: 55.6%	Styro-foam:11.1%
v/v/	Styro-foam: 19.4%	Rubber: 16.7%
o/o/	Textured (dot) rubber: 30.6%	Slick paper: 13.9%
a/a/	MFP:11.1%	Silk: 11.1%

Table 3: The two highest percentages of the letter-sound-material mappings for each pair.

consistent mappings involving *p/p/*-purple ($p<0.01$), *m/m/*-pink and orange, *d/d/*-black, and *g/g/*-green ($p<0.05$, see highlights in Table 2).

We also analyzed the material frequency distributions. As shown in Figure 4, the *f/f/* pair elicited the material feather above all others. We then recoded the two trails and found extremely significant results in pairs of *f/f/*-feather and *m/m/*-fur ($p<0.001$). Significant results were also found in pairs of *m/m/*-velvet, *n/n/*-cotton, *g/g/*-linen, *b/b/*-plastic grid, *d/d/*- plastic grid, *t/t/*-metal foil paper, *p-/p/*-styro-foam, and *o/o/*-textured (dot) rubber ($p<0.05$, see highlights in Table 3).

Interpretations for the consistent mappings

Thematic analysis of the interviews showed that participants' choices were significantly influenced by literacy for those letter-sound pairs that are literacy-biased. For example, many participants explicitly mentioned that they thought about the word blue when seeing the letter *b* and hearing the */b/* sound. Participants also used associated words and metaphors to select colours. For example, five participants mentioned that they chose black for *d/d/* because of the word *dark*. However, participants were inclined to make the mappings based on the characteristics of letter sounds rather than the symbols for those letter-sound pairs that are either without strong literacy-bias or fail to quickly make them think about associated words. For example, 10 participants said they mapped warm colours (i.e. pink, yellow and orange) to *m/m/* because the sound of */m/* was soft.

Compared to colours, participants' responses to materials were more consistent. We found that their choices were largely influenced by the characteristics of sounds rather than symbols or the literacy meanings of the associated words. Twelve participants reported that they chose soft materials such as felt because of the soft and comfortable letter sound of */m/*. It is interesting to notice that we initially thought that most participants might associate the *f/f/* with the word *feather*. However, in the post-interviews, the participants mentioned they selected the material feather just because the sound */f/* was light and the touch of the feather gave them the same feeling. In contrast, participants tended to associate the quick-and-short letter sounds such as */b/, /d/, /p/* and */t/* or hardly pronounced letter sounds like */v/* to materials with hard (e.g. metal foil paper) or hard textured surfaces (e.g. plastic grid). Results also indicated that most participants (14 out of 18) automatically created a continuum and attempted to put each letter-sound pair into an appropriate position.

The potential influence of the first language

We found some influences of participants' first language on their choices. For example, one participant (P5) reported that he thought about the word sun（日）for the r/r/ pair since in the Chinese alphabetic language, the word (日) was spelled as "ri". We did not notice a large influence of the first language, probably because (1) participants had a medium level of English knowledge so they intended to answer these questions in the English context although we did not ask them to; and (2) most of their selections, particularly the material selections, were based on the nature of sounds rather than the literacy/language level.

Discussion and Future Work

The findings of this study could have potential to inform the future designs of colours and materials in the digital

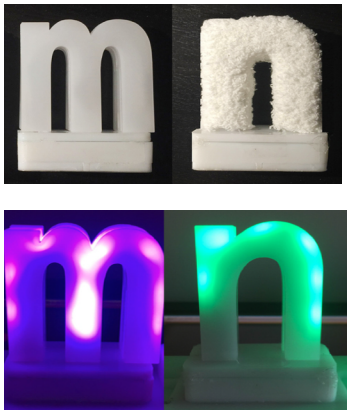

Figure 4: Using contrasting materials (hard v.s. soft materials) or colours (pink vs. green) to differentiate /m/ and /n/ sounds.

and tangible reading products for EFLs. In previous products, the opportunity to utilize colour and material cues for letters was underutilized [8,9]. By intentionally using such mappings (e.g. make *m* as *pink)*, designers could provide more effective means to help learners to learn and memorize basic letter-sound pairs. Another use could be to intentionally present contrasts to help learners to distinguish similar letters or letter sounds by using contrast (Figure 5). These contrasting cues may help learners to "see" and "feel" the differences. One last finding is the potential influence of literacy, which suggests designers could cue and reinforce particular mappings through additional pictorial cues that mirror the mappings.

In future work, we will consider narrowing down the materials based on the results of this study and perhaps providing canonical examples for materials consistently associated with sounds, as well as alternatives. We will extend our learning materials to whole alphabets and conduct a large-scaled study with participants with various first languages (e.g. Chinese, French, English) to reduce cultural influence. Lastly, we will consider applying the design strategies we proposed to a tangible reading prototype with texture cue and investigate its effectiveness in supporting the learning of letter-sound pairs for EFL learners.

Acknowledgements

We thank the students at Zhejiang University of Media and Communications to participate in our study.

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