SpeechBlocks: A Constructionist Early Literacy App

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ABSTRACT
This paper introduces SpeechBlocks (SB): a smartphone app that allows children to explore spelling principles in an open-ended way. Children rearrange letter combinations through direct manipulations and instantly hear each combination pronounced back, whether or not a conventionally spelled word is formed. We evaluated SB with a group of 16 preschool children ages 4 and 5 in a pilot consisting of 16 sessions over the course of two months. Qualitatively, we found that (a) the app facilitated children's engagement, sense of authorship and self-efficacy, (b) SB evoked significant amount of social interactions between children around literacy activities, and (c) support of nonsense words and remixing contributed to these factors. In addition, fine-grained log data of children's interaction with the app showed promise as a viewpoint into their literacy skills and interests.

ACM Classification Keywords
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Author Keywords
constructionism; early literacy; phonological awareness; phonics

INTRODUCTION
The ability to read and write is an essential skill for a person in a modern society. Yet this is a challenging task for a child to master – especially in languages that do not adhere to the phonemic principle, such as English and French [26]. Smartphones, which became ubiquitous in developed countries and is steadily gaining prominence around the world [16], have the potential to support children in this undertaking. Among other advantages, they offer (a) a mode of interaction that is intuitive, natural and engaging for children; (b) a possibility to bring educational activities from the classroom into homes and other informal learning environments; (c) a possibility to enable personalized learning experiences and (d) a promise to reach underserved families [21]. Currently, there is a great number of educational apps designed to support literacy learning. However, the overwhelming majority of these apps are within the instructionist paradigm – they present the child with a task or a puzzle which has a single pre-determined correct answer [24]. The validity of such an approach has been questioned in light of findings from the science of learning [7].

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Figure 1. Sblocks.

In his foundational work *Mindstorms*, Seymour Papert suggested the key learning affordance of computers (which smartphones essentially are) is not to "program the child" through tasks and answers, but instead to be a tool for exploration and self-expression through the construction of artifacts [14]. This paradigm, known as constructionism, has since been shown to promote deeper learning and facilitate intrinsic motivation and self-efficacy (see, e.g., [18]). However, there are very few literacy apps implemented within this paradigm. Additionaly, to the authors' knowledge, there has been no published research exploring the potential of constructionist mobile apps for literacy learning. These factors motivated us to create SpeechBlocks and conduct the present study.

In SpeechBlocks (SB), children rearrange letter combinations by pulling them apart and putting them together with their fingers. Each combination, whether or not it represents a real word, is then pronounced aloud by a speech synthesizer[1], creating instant feedback to the child. Such interaction was designed to help children acquire written text decoding skills (as elaborated in the *Literacy Research Background* section). In addition, SB provides a medium for learners' self-expression.

We conducted a pilot study with SB to identify how children would interact with a constructionist mobile learning app and to inform further development of such technology. We were specifically interested in the following questions:

(a) Would children engage with SB?

(b) If yes, what would they do and what would they build? E.g. their names? Names of things that surround them? Random rearrangements of letters?

(c) What kind of activities can enrich their experience with SB?

(d) Would children play with SB socially?

We present qualitative and some quantitative observations that shed some light on these questions. Our results have implications for developers and designers of early literacy technologies.

While this paper focuses on SB on its own, we believe that the greatest potential lies in SB being a part of a larger system. We are exploring possibilities for a technology that would facilitate the formation of a supportive informal learning environment around the child. Such environment would include peers, parents and learning experts. The experts would act as guides, rather than instructors, by providing feedback to the parents and remotely adjusting the workings of the literacy apps. The expert's decision process could be supported by an automated analysis of the digital traces of the childrenâĂŹs interactions with the device. We believe that a constructionist approach is crucial for creating this type of supportive learning system, and SB is our first step towards this goal.

RELATED WORK

Talking Typewriter

In 1960s, Moore [12] conducted extensive experimentation on building "autotelic responsive environments." By this he meant environments where a child: (a) is driven by intrinsic motivation, (b) could explore freely, (c) receives immediate feedback, (d) determines the pace of events, (e) makes full use of his/her capacity to discover various relations, and the very structure of environment facilitates such discoveries. Moore's environments included "talking typewriter" which, in addition to printing letters, could also pronounce them back to the child. In certain modes the typewriter also pronounced the words being typed (though, in opposition to SB, it only handled real words). Moore found it necessary for efficient learning to provide some structure to the exploration. He did this by constraining the action space (e.g., blocking some keys on the keyboard). A laboratory assistant would monitor the learner's activity with the device and transition the child to a more or less structured setting should s/he show the signs of boredom or frustration. Moore also took care to provide meaningful context for typing activities: children wrote materials for their own newspaper. The "talking typewriter" was to a large extent based on the same pedagogical principles as our approach.

Talking Blocks

In 1980s, a student of Seymour Papert, Aaron Falbel, created an open-ended computerized environment for writing [6] based on the postulate that children have a natural capacity for learning given a proper environment to explore. His system allowed learners to experiment with making words by dragging blocks, which represented phonemes, into a working area and arranging them there. The blocks did not form combinations as in SB – instead, their positions were used to fine-tune the pronunciation, with horizontal intervals controlling the duration of each phoneme and vertical coordinates controlling the pitch. Falbel felt it was important to give children this opportunity to play with the sounds. A speech synthesizer was used to pronounce the resulting arrangement phoneme-by-phoneme, supporting both real and nonsense words. A particularly unusual and interesting aspect of the design was the emphasis on making the spelling systematic, as opposed to adhering to the rules of English orthography. This was influenced by the research on invented spelling [17]. Falbel represented each phoneme with the grapheme that it is most commonly associated with, leading to spellings like "tawking blawks" for "talking blocks." We chose a different approach, as discussed in *Design* section.

Tiggly

Tiggly Story Maker[2] and its derivative, *Sesame Street Alphabet Kitchen*[3], are early literacy apps which allow for a limited degree of experimentation. Each app displays a short string of consonants with a space in-between, that can be filled with a vowel to form a word. *Alphabet Kitchen* presents this process as making word cookies using letters cookie cutters. The child can put any vowel in the space, and the result is pronounced whether or not it constitutes a valid word. In the latter case, in *Tiggly*, a spring throws a letter away afterwards, while in *Alphabet Kitchen*, the Cookie Monster makes a funny but encouraging remark (e.g. "BOD – don't know that word – probably some sort of French pastry"). If the child creates a real word, an object that the word stands for appears (in *Alphabet Kitchen*, this is in a form of a cookie). In *Tiggly*, these objects interact with each other, allowing for some storytelling. However, the possibilities for creation in both of those games are limited, and they can not be considered constructionist.

Word Wizard

Word Wizard[4] is a mobile app that allows children to build words by dragging letter blocks onto a grid. The learner instantly hears the words pronounced back by a speech synthesizer. Incomplete and nonsense words are supported. Similarly

[1] We chose IVONA (https://www.ivona.com/) because of pronunciation quality and possibility of phoneme-level control.

[2] https://www.tiggly.com/tiggly-storymaker

[3] https://www.tiggly.com/sesame-street

[4] http://lescapadou.com/LEscapadou_-_Fun_and_Educational_applications_for_iPad_and_IPhone/Word_Wizard_-_Talking_Educational_App_for_iPhone_and_iPad.html

to the Moore's design, Word Wizard has several constrained modes intended to help children spell particular words.

To our knowledge, there have been no published studies examining how children interact with *WordWizard*. It is likely that many findings in our present study apply to that app as well. However, there is a significant difference between *WordWizard* and SB in their interaction paradigms. *Word Wizard* only supports building words letter-by-letter by arranging letters on a fixed grid. In contrast with that, in SB, letter blocks snap to each other, not a grid, which allows for tinkering with existing words and remixing them into new ones. As shown in the *Results* section, the ability for children to remix pre-existing words in SB creates a significant new affordance in children's play and supports their engagement. Additionally, it creates more opportunities for exploration by letting the child not only synthesize, but also "analyze" words by breaking them down into parts. Furthermore, *WordWizard* was designed to be a standalone app, while our goal is to incorporate SB as a part of a larger human-machine system.

Text-Based Open-Ended Games
There are several games that allow children to use text for open-ended creation. Notable examples are *CBC4Kids Story Builder* [1], *Mobile Stories* [5], *StoryTime* [9], *Arthur's Comic Creator*[5] and *Scribblenauts*[6]. However, these games are designed for type or word-dragging input and are not aimed for exploration of relationships between spelling and sound.

LITERACY RESEARCH BACKGROUND
Behavioral [3] and neurological [26, pp. 145-155] evidence indicates that written words in human memory are linked to pronunciations, not directly to meanings. Thus, in order to acquire literacy, it is essential to learn the mapping of spellings to pronunciations. Experienced readers recognize familiar words as a whole [3]. But before achieving that, a reader needs to utilize decoding skills to reconstruct likely pronunciation using common spelling-to-sound regularities. Performance on reading nonsense words is used to assess children's ability to decode [23].

One prerequisite of decoding is the awareness that words consist of smaller sounds – phonemes (see, i.e. [8, 4]). The challenge for a learner is that phonemes are co-articulated in speech and thus hard to separate. Another component is the knowledge of how phonemes map to letter combinations. Yet another prerequisite is the knowledge of blending: how separate sounds combine into a word. In languages with complex orthography, such as English, these skills are still insufficient, because the sounds of letters and letter combinations are very context-dependent. Thus, learners have to acquire pronunciations of larger "sight chunks," such as rimes and morphemes [3][26, p. 128], which tend to be more consistent. They also have to apply analogical reasoning to infer pronunciations of novel words from known ones [3].

[5] http://pbskids.org/arthur/games/comiccreator/
[6] https://www.scribblenauts.com/

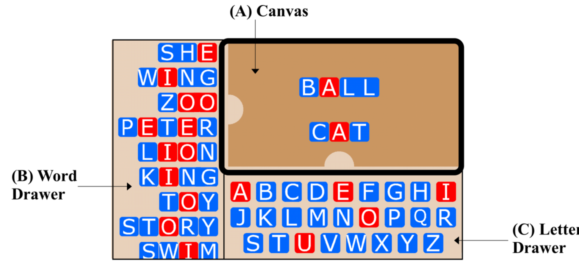

Figure 2. SpeechBlocks' Interface Components

Some educators, including Maria Montessori, taught writing before reading [11]. Montessori argued that writing is cognitively simpler, because it does not require the child to have a mental model of the author. Another important advantage of writing is that it allows children to perceive authorship over what s/he wrote and empowers them through the ability to leave a lasting mark in the world and communicate with other people [22, pp. 77, 85]. Many children are drawn by these factors even before they master writing: They create imitations of books and mail [22, pp. 82, 114]. To facilitate the sense of empowerment, practitioners suggested to maintain a "me museum," where the child's literacy accomplishments are preserved [22, p.54]. Other successful practices include surrounding children with meaningful contexts to exercise their literacy skills: maintaining a classroom "newspaper," labeling personal belongings with their names, writing letters inviting people to the class, etc. [22, pp. 22, 24] Fostering human connections, both with adults and with peers, is another important ingredient to successful learning [22, pp. 24, 85][10, pp.193-223].

One important phenomenon of early writing, related to our support of out-of-vocabulary words, is invented spelling [17]. Children who are not yet familiar with conventional orthography sometimes come up with their own spelling systems, often more logical and systematic than the conventional one. It has been found that invented spelling can efficiently be utilized to help development of phonological and other early literacy skills [4, 20, 13] and can serve as an indicator of children's reading level . In addition, invented spelling facilitates early access to the literacy culture [20] and may help the child to develop a love for it.

While we tried to support development of decoding skills, our goal was also to make technology that would help learners to feel a sense of authorship and connect to other people through their activities. Additionally, we strived to build an app that could be used as a component of larger activities in which children can use writing in personally meaningful ways.

DESIGN

Interface and Interaction
The SB interface consists of a single screen divided into three areas (Fig. 2). The canvas, which normally occupies almost the entire screen, serves for tinkering with letters and words. On the sides of the canvas, there are retractable word and letter drawers. The word drawer contains a selection of words that

can be used as prompts and as a material for remixing. It also stores words created by the child – a word can be dragged onto the word drawer to be saved there. The letter drawer holds individual letters. The drawers are made retractable to save the screen space, which is particularly limited on smartphones.

The blocks in the canvas are connected to each other like LEGO bricks. The user interacts with block combinations through tapping and dragging them with their fingers. Placing two fingers on one block combination and moving them in opposite directions will cause the combination to split into two (Fig. 3, a). Putting two combinations end-to-end and "pressing" them against each other will cause them to merge into one (Fig. 3, b). Every time a split or merge happens, the speech synthesizer immediately pronounces the outcome of the manipulation. Block combinations are also pronounced when tapped.

This simple interaction allows the learner to explore a wide range of language regularities in a uniform way. S/he can decompose a word into constituent sounds by simply pulling it apart. By merging strings, s/he can witness how individual sounds blend together. In the process of play, the learner is exposed to the sounds that word chunks of different sizes make. When a learner strips off a part of a word and replaces it with something else, s/he observes an analogical transfer of pronunciation.

SB uses different colors for vowel and consonant blocks. Such differentiation is a quite common practice: it is utilized in Montessori's *Movable Alphabet*[11] and in a variety of educational technology such as *Alpha Writer*[7] and *Touchtronics Letters*[8]. Analysis of invented spelling shows that vowels appear play a special role in the process of writing acquisition [20], which makes it reasonable to emphasize them.

We used uppercase letters for the blocks, but this choice is less straightforward. It has been argued that uppercase letters are more easily distinguishable by a child, since none of them looks like a mirror image of another (in contrast with such lowercase letters as "b", "d", "p" and "q"). For that reason, uppercase letters are taught first in several widespread literacy curricula, such as *Handwriting Without Tears*[9]. On the other hand, lowercase letters constitute the majority of printed text, and familiarity with them may contribute more to children's emergent literacy skills. They are used in literacy materials such as *Movable Alphabet*, as well as every app considered in this paper. In light of this ambiguity, we used a practical consideration to select uppercase letters for our first design: they could be more readily fitted on a square block.

We believe that design of SB is applicable to a variety of touch-screen devices, from tabletops to tablets to smartphones. However, we currently focus on the latter, which are most readily available in home settings. We believe that informal learning in those settings is where the greatest potential for SB lies. A tradeoff which have to be accepted with smartphones is the limited screen size. When at least one of the drawers is extended, it covers a large part of the canvas, leaving relatively little space for play. While we saw children having minor difficulties with that, it doesn't appear to be a major problem.

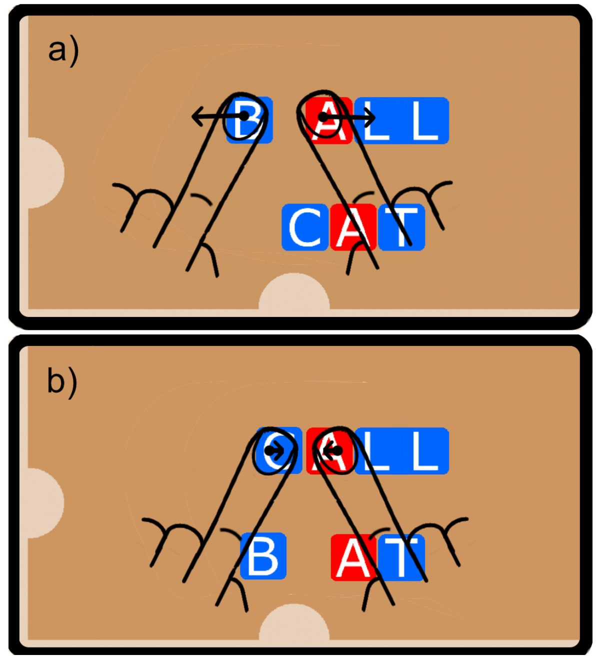

Figure 3. Basic Interactions with SpeechBlocks

Design Inspirations

We attempted to create a literacy app which would allows learning through child-driven, persistent exploration, similar to one that occurs in Montessori classrooms. For instance, Lillard [10] describes a child repeating an activity with a Montessori material 42 times in a row, despite deliberate attempts to disturb her – until suddenly she stopped, as if she reached an "aha" moment. She apparently grasped the principle and never returned to the activity again. Montessori and constructionist approaches both view learners as competent pattern discoverers who are able to learn regularities of the world (in our case – the functioning of written language) on their own if the environment is sufficiently rich and transparent. To allow for extended exploration, we made SB combinatorial: children are able to compose letter blocks in any possible order. To create a safe space for experimentation, we excluded the notion of "right" and "wrong" from our design: If a child creates nonsense words, they are pronounced just like regular words. This consideration also led us to avoid game-like rewards. This decision contrasts with the recommendation of Chiong & Shuler [2], who identified such rewards as an important factor of engagement of children with educational mobile apps. However, it is in line with the large body of research indicating that external rewards are detrimental to exploration and creativity (for an overview, see [10, pp. 152-172]). We found SB to be engaging for children even in absence of game-like dynamics.

We were also inspired by work of Resnick and Rosenbaum, who emphasize the importance of "tinkering" [19]. They define it as "*playful, experiential, iterative style of engagement*",

[7] https://montessorium.com/app/alpha-writer
[8] http://juniorlearning.com/touchtronic-letters.html
[9] https://www.hwtears.com/hwt/why-it-works/teaching-order

and provide guidelines for building designs that support it. Our design is in line with some of those guidelines. First, it provides instant feedback to the child. Second, in SB, it is easy to get started without much preparation and knowledge. Children can begin by remixing existing words from the word drawer to make nonsense words. The results are often surprising and possess a humor value that is recognized by children. The emphasis on remixing is one important difference between our app and earlier works, such as Talking Blocks and Word Wizard. Third, our study shows that SB provides many distinct avenues for children's creativity. We believe that diversity could be furthered by integrating SB into larger constructionist activities.

The Choice of the Block

An interesting design question that requires further investigation is what exactly should act as a block. A good building block should retain its core function regardless of the way it is combined with others. The core function of a talking block is to produce a certain sound. From this standpoint, the choice of letters as blocks is not optimal, because what letter encodes strongly depends on its context. Similarly to Falbel [6], our original approach was to use graphemes for blocks. However, we found some difficulties with it. First, graphemes did not appear natural to children: During our initial trials, they were frequently frustrated that they could not pull the multi-letter grapheme blocks apart. Second, the sound of graphemes, particularly single vowels, is still significantly dependent on the context: One grapheme may represent multiple sounds and one sound may be represented by multiple graphemes. Unlike Falbel, we did not want to enforce one-to-one phoneme-grapheme correspondence within the system: While we wanted to allow invented spelling in our app, we did not want to force it. It would create a disconnect between the app and the surrounding literacy culture (children books, environmental print, etc.), which is the foundation of children's emergent literacy. We decided to use a compromise approach: whenever several consecutive letters form a grapheme (e.g. a vowel digraph such as *"ea"*, or a consonant digraph, such as *"th"*), we visually combine them into a single block. However, internally, they are still treated as multiple blocks and can be pulled apart. The intent of this dynamics is to allow incidental learning of common letter combinations.

It is also possible to choose an "inverse" approach, when the sound of a block stays constant, but the displayed combination of letters changes based on the context. For instance, a block representing phoneme ɑ would look like "a" in "star" and like "au" in "laugh". The advantages and disadvantages of each approach are worth examining in a separate study.

PILOT

Overview

To see how children interact with SB, we conducted a pilot study with a group of preschool children over the course of two months. We observed children playing both freely and in context of structured activities. We also experimented with different supplementary materials to use alongside of the app. Since the purpose of the study was not to prove a particular hypothesis, it did not include a control group.

The study was conducted in a daycare center at a university in the Greater Boston area. In this environment, teachers practiced splitting children into groups of 4 and rotating them between different activity stations every 15 minutes. We established a literacy station: a table with phones and supplementary materials on it. One researcher was seated at the table to assist children when they had questions and guide them through activities (if present). Another researcher took notes. The station was active two days a week. Although the children had to come to the table during their rotation, they were free to leave as early as they wanted. The fact that children were coming to the literacy station in groups of four contributed to the social dynamics observed.

We used three ways to gather the data about the sessions. The first way was the observation notes, which were free-form. Second, we recorded a video of all sessions, with the exception of one group, for which we did not obtain the consent to record from all parents. Third, the app itself maintained a very detailed log of all user interactions that allowed us to completely reconstruct and analyze everything that was happening on the screen during each session.

During the pilot, we used an earlier version of SB that lacked some of the features described above: It did not display composite blocks for "sight chunks" and it was not capable of saving words that children constructed. To compensate for the lack of saving function, we provided each child with a journal, where us or children themselves could write words that they wanted to preserve.

Participants

We had 16 participants ages 4 to 5 years old: 12 girls and 4 boys. They had no speech and hearing disorders and were typically developing. They were mostly children of faculty and staff at the university. Thus, they were likely to have rich literacy environments in their homes.

The children's literacy skill varied greatly: some were already able to spell simple words, whereas others did not know all the letters yet. We conducted a pre- and post- assessment of the children's literacy and language abilities using the CTOPP-2 Sound Matching Subtest. On the pre-test, 4 children scored below 50th percentile, with some scoring very low. Interestingly, on post-test all of the children scored above 50th percentile, and 14 out of 15 children (one child's results were discarded due to no pre-test) showed increases in their CTOPP scores. The overall increase was statistically significant (p-value = 0.003). This improvement happened in a short period of time (10 weeks). While the absence of control group does not allow to attribute these results to SB, they warrant a study of effectiveness of our app.

Activities and Complementary Materials

During the first day, the sessions were set up as free play. The children were shown how to use SB, but no specific activity was suggested, and we observed how they use the app on their own initiative. On the second day, we tried to provided themes – e.g. animals, party, food – as a prompt for the children. However, the children mostly ignored the themes and continued with free play. On days 3 and 4, we put a set of

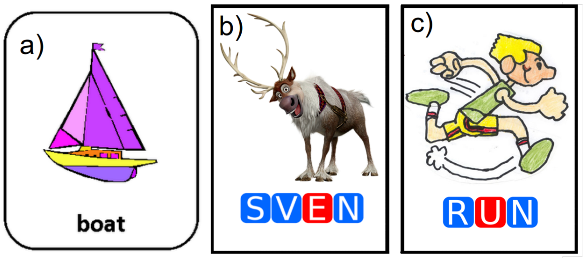

Figure 4. Articulation (a), character (b) and action (c) cards

articulation cards (Fig. 4a [10]) on the table. They are normally used to practice common pronunciation patterns, but we were interested in using them as prompts to give children more ideas on what to spell. On days 5 and 6, we attempted a structured activity similar to Mad Libs[11]. The children were read a story with some gaps and asked to complete the story as they like by creating any words, real or nonsense, with SB. On days 7 and 8, we reverted back to the free play setup.

The idea for another learning material was indirectly suggested by the children themselves. During the very first day of play, one child merged two instances of *ZOO* from the drawer into *ZOOZOO*. When the synthesizer pronounced it back, the child exclaimed excitedly: "This is Zazu from Lion King!" This excitement was picked up by another child, and they continued to make *ZOOZOO* during almost every session. In response to that, we created a new set of cards, mimicking the articulation cards, but using cartoon characters (Fig. 4b). The name of the character was spelled in the font resembling SB, to encourage children to make the word in the app. To promote progress towards sentences and storytelling, we later added cards displaying verbs (Fig. 4c; introduced to children as "action cards"). Finally, we recorded some of the sentences children said and the next day presented them on a new set of cards (Fig. 5). The sentences made in SB were compiled into a small "book" that was given to the group at the end of the study.

Video Annotation and Analysis

To capture the difference of children's behaviors across differently structured play sessions, we annotated video recordings from three days: a free play day, a day with Mad Libs-like activity, and a day with character cards. We used recordings of only 10 children who were present on all three days. To observe activities on the phones within the context of activities and conversations in the classroom, we implemented a tool called Play Observatory (Fig. 6). The tool displays synchronized video recording of the children's play and simulations of their SB screens reconstructed from the log files.

Our first-hand observations in the classroom made us most interested in three dimensions of the play activities: manifestations of self-efficacy and authorship, intentionality of words

[10]Image sources: http://testyyettrying.blogspot.com/2011/07/final-t-free-speech-therapy.html, http://hero.wikia.com/wiki/File:Sven.png, http://www.clipartbest.com/run-cartoon

[11]http://www.madlibs.com/

Figure 5. Sentence card

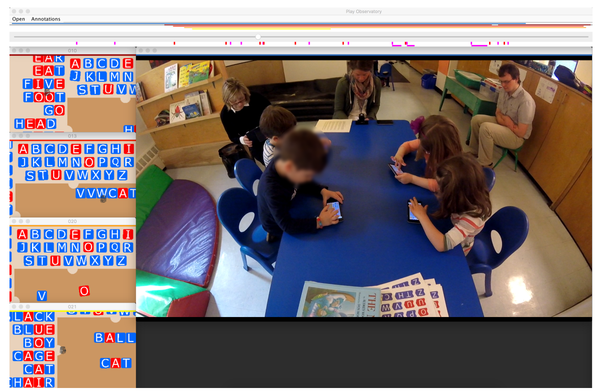

Figure 6. Play Observatory.

and actions, and social interactions between children around the app and materials. To capture them, we designed a behavioral protocol that was inspired by two frameworks: Four Indicators of Learning [15] and the ILAUGH Model of Social Thinking [25]. We don't provide the detailed description of the protocol here, since the behaviors that we looked for are described in the *Results* section.

RESULTS

Types of interaction

Children used SB in a variety of ways:

Making nonsense words through remixing. This activity was the most popular during the first days of the play. Children would most frequently concatenate several words from the drawer together to achieve results like *ZOOCATBALL*.

Patterning. Participants built letter combinations letter-by-letter in order to see the outcome. In many cases, letters either appeared in alphabetical order, or were repeated multiple times (e.g. *ZZZZZZZZZZ*), or were interchanged (e.g. *AJAJAJA*). Some children copied the sound that the speech synthesizer made after adding each new letter. One child commented: "*It is saying buzzzzzzzz, just like a bee*".

Spelling names. Children would spell both their own names and the names of their friends. Names were often the first real words that they tried to spell. It was common for them to persist on this self-imposed task over the course of many days despite initial unsuccessful efforts. As a result, there was often an evolution in the way the name was spelled, towards correct spelling. For instance, for a child spelling name Addia[12], the evolution appeared like this: *DD*, *ADD*, *ADID* and *DDAA* (day 1); *ADD*, *ADDI* and *ADDIA (day 4)*; *AGIHD* and *ADDE* (day 5); *AWI* (day 12); and finally 4 occurrences of *ADDIA on days 11 to 14*. Children would frequently combine their names with other words, particularly the names of cartoon characters (after the introduction of character cards). An example of this could be *BUZZALEX* (referring to a Pixar's character Buzz Lightyear). When we asked the child what this word meant, he replied: "*It means that I am Buzz!*".

Creating words and sentences using the cards. Children created less than 10 words inspired by the articulation cards. That stands in sharp contrast with character cards, which were actively used by almost all children (and only one child did not use them at all). Children often picked three to five character cards at the beginning of the session, arranged them in a row and throughout the whole session built the characters' names. The font imitating SB that was used on the cards turned out to be very helpful for children, because they were able to find necessary letters in the app by visually matching them with those on the card. They were unable to do the same with articulation cards, which used lowercase and a different font. In one case, there was a moment of discovery when a child copied a word from a card and realized what the word says only after the synthesizer pronounced it; it lead to her surprise and excitement. Action cards were also actively used after their introduction. However, children rarely (1 occurrence) made a complete sentence one the screen. Instead, they would made words one-by-one and delete them, or make one word and say the sentence verbally. After the introduction of the sentence cards, about a third of the children engaged in copying sentences from them.

Using SB as a reference to write words in journals. Children preferred to write down words on their own. In many cases, they were not fully able to write and would carefully redraw letter shapes, using the image on the screen as a reference. Several children turned this into a separate activity: Instead of spelling the words in the app, they copied it from the word drawer. Notably, some were unable to read the words yet, so they utilized the pronunciations generated by the speech synthesizer to find an interesting word to copy. There were 3 children who dedicated the entire duration of at least one session to this process. It is possible that this unusual activity resulted from a greater sense of agency and relatedness to writing inspired by the constructionist setup. This question needs further investigation.

Making everyday life words: Participants created words that were inspired by their surroundings, day-to-day activities, events happened in their lives, etc. Example words include: *LOV* (love), *MOM*, *POPCORN*, *BNGA* (bang), and *SINK* (an item that could be observed in the classroom). Such words were infrequent: we found only around 10 occurrences of such words in the entire data. In addition, there were several cases when children verbally expressed the desire to make a word related to their experience, but did not. We believe this was because the children did not have the proper scaffolding to make the word on their own.

[12]Children names were changed to protect their identity. The sequence of name spellings is taken from data, but altered by substitution of the corresponding letters.

Character of Interaction

We found that children utilize the merge functionality 8 times more frequently than the split one. Furthermore, most of the splits were generated in process of self-correction, when children were rebuilding words that did not sound as expected. Only 4 children split words in order to either explore what the parts sounded like or in order to create building material for other words, and each child did that only a few times.

Although we do not know the exact reason why splits were less used, we can see several possible causes. First, the limitations of the SB version used in the pilot may have made splitting less convenient than merging: A child's finger could accidentally touch a neighboring block, leading to split happening in a wrong place. Second, children seemed to be interested in building long words, as evident from their exclamations, such as: "*I am making such a long words!*" and "*I made the longest word ever!*". Since splits lead to shorter words, they might have been less interesting for children. Third, children may have perceived splits as undoing their work or existing meaningful words, rather than creating something new.

As mentioned above, we think that splits provide important learning opportunities. It is a question for further investigation whether splitting behavior can be encouraged by proper scaffolding.

Engagement

Children used SB very actively during initial days. This can almost completely be attributed to the fun of making nonsense words by remixing words on the drawer, as evidenced by frequent laughter and comments such as:

- (laughing) "*ZOOBALLBALL! What's that like?*" (later) "*ZOOBALLBALL – that's what I say!*"

- (hearing a word made by peer's phone) "*CUPEAR!*" (laughing) "*Can I see? Can I see how you spelled CUPEAR?*"

The positive influence of that slight amounts of absurdity have on children's engagement with educational apps is similar to observations of other authors [2]. As the entertainment value of making nonsense words started to exhaust itself, the engagement started to drop.

Children's engagement dropped even further when we introduced the highly structured Mad Libs-like story activity. While some children enjoyed the activity, most felt frustrated. A few children explicitly said that they were bored. This was caused by the fact that children wanted to create specific words to complete the story (e.g. one child wanted to create *QUACK* for a sound that the dog in the story makes) but did not yet have the skills to do this on their own, and assistance that we could provide was limited. This situation occurred despite our explicit statement that we welcomed nonsense words that could complete the story and make it silly. The very nature of activity caused it to be too inflexible for children to utilize their existing skills.

Engagement visibly recovered when character, action and sentence cards were introduced. Children started to set challenging spelling goals for themselves more frequently.

There are two additional bits of qualitative evidence showing generally-good level of engagement with the app. First, children were often (57 cases in the 3 annotated days) repeating the words that the speech synthesizer was producing. Second, according to the teachers, several children continued to talk about SB and the words that they made after the sessions. Third, the last two sessions were spontaneous. We only planned to wrap up and present children the book that they made, but they requested that we give them the phones and continued to joyfully make words.

Self-Efficacy and Authorship

The children took pride in making words in SB, as evidenced by their exclamations:

- "*I spelled LALLA! That's what my name says.*"

- "*I can spell ZIVVY with mine* [phone]*!*"

- "*Look! I spelled BUZZ!*"

- "*I made so many words!*"

We counted 39 such expressions within the 3 annotated days. We attribute such exclamations to a sense of accomplishment fostered by either producing something interesting and fun (even by accident) or setting up a goal for oneself and successfully carrying it over. Both cases were enabled by the free-form nature of the app, and we surmise that is is harder to achieve the same in the context of a pre-described, puzzle-like activity where children have less agency.

Interestingly, the children who scored below 50th percentile on CTOPP-2 pre-test produced much more verbal signs of self-efficacy: 6.25 occurrences per child within the 3 days, as opposed to 2.33 occurrences per child for children who were above 50th percentile (p-value 0.013, using t-test). This evidence suggests that SB may be more compelling for children who experience reading difficulties, allowing them to meaningfully engage and feel a sense of accomplishment. This is a very desirable characteristic, since children who struggle with reading are often most in need of support and motivation.

Another indicator that children felt a sense of ownership of their work is manifested in children's desire to take their journals and keep them. One child even asked: "*Can we keep them forever? Until the end of our lives?* "

Goal-Setting and Planning

Setting goals for oneself freely and executing plans to achieve them is another manifestation of learner agency. Children's self-directed speech indicated that they did that. For example: "I'm going to make Simba. I need S, I, M... I'm writing about Lion King today." We found 59 phrases like this. They were almost always unprompted: Children were naturally talking about their plans and goals.

Social Interaction

Even though SB did not have any explicit features for social play, children frequently engaged in a variety of social interactions related to their activity with the app. In the 3 annotated days, we counted about 600 micro-occurences of all the behaviors below:

Displaying their work. As mentioned above, children took pride in their creations and displayed them both to adults and to their peers.

Observation. Children's curiosity was often piqued by the sounds produced by their peers' phones, and they looked at their screens. In one case a child was not actively interacting with the phone in the course of several sessions, but instead was watching other children's activities very attentively. Eventually she became an active player again. It seems that the observation helped her to gain confidence and ideas on what to do.

Idea borrowing. Children imitated creation of others that they liked. For instance, when one child spelled *LOV*, a child from another group heard the sound and reproduced the word during her turn.

Shared play. Participants would sometimes play in close coordination with one another. In one instance, a child made a nonsense word *WCAT* and showed it to a peer. The peer, who had *VWCAT* spelled, remarked: "*You did the same thing as me! You have to do exactly the same thing*". She then bent over her friend's screen to find letter *V* together with her. When the letter was found and added, she said: "*Another V! Let's add another V!*", and both of them did that. They continued to make words together for some time afterwards.

Assisting each other. Children asked each other questions such as: "*Oh! Do you know where T is?*" (on the letter drawer) or "*Can you help me to spell your name on my phone?*"

Conversation. Participants connected the words pronounced by SB to their life experiences, e.g. saying "*I have a dog*" after hearing someone's phone pronouncing *DOG*. In many cases other children responded, resulting in several turns of conversation.

Storytelling. Children produced verbal descriptions of imaginary situations involving words they made in the app:

- (Repeating after the speech synthesizer) "*BALLCATTOYZ...*" (noticing that "toys" were accidentally made) "*Wait, I spelled toys?!*" (speaking to another child) "*Oh, you know what? You know why I spelled it? Because it is cat playing with ball toys – that's why I spelled it.*"

- (responding to a researcher's question about Olaf) "*Olaf likes warm hugs.*"

We found 37 instances of this behavior over the 3 annotated days of data. About two thirds of those instances were child-initiated, whereas in other occasions children responded with a story to a question asked by a researcher. Most of these cases (29) occurred on the day when children used character cards – significantly more (p-value = 0.01, using paired sample t-test) than in the other two settings. This shows how prompts within a constructionist literacy activity could reinforce children's meaningful engagement around storytelling.

Early Literacy Phenomena Visible in the Data

We found that the log data from the phones captured two phenomena that often occurred during the early stages of literacy acquisition: omission of silent *E* at the end (e.g. spelling *LOV* instead of *LOVE*) and reversal of text direction (e.g. spelling *ASLE* instead of *ELSA*). For the latter children, the text direction phenomena also showed up in their journals: While writing words, they placed letters completely randomly (not even in one line). Nevertheless, that they considered their work proper words, as evidenced by phrases like "I wrote all of this!". Apparently, at their stage of literacy development, they were unaware of the role of letters' spatial arrangement. In one of the cases of text reversal, the child noticed the unexpected pronunciation generated by the speech synthesizer, and learned about the directionality of text from a researcher's explanation.

DISCUSSION AND FUTURE WORK

Current study was conducted with children from families with relatively high socioeconomic status (SES). However, the promise of mobile learning technology partially lies in its capacity to reach underserved households. From that standpoint, it is of interest to conduct evaluation of SB with children from more diverse socioeconomic backgrounds. Outside of the scope of the study, we had opportunities to present SB to such children and found that they exhibit mostly similar engagement and patterns of interaction.

Instant feedback feature prompted a variety of educationally useful behaviors. Most prominently, it contributed to literacy-related social interactions that provide opportunities for peer learning. The emphasis on remixing, which was distinctive for SB, helped children to produce interesting results early on, contributing to engagement and self-efficacy.

We found that scaffolding materials were important for learners to maintain meaningful engagement with the app. Their role was twofold. First, they served as prompts, giving children ideas of what to make. The efficiency of character cards, as opposed to articulation cards, highlights how important it is for such a material to tap into children's interests, rather than focus solely on its educational function. Second, the materials acted as support, giving children a reference on how to spell certain words. Children frequently wanted to build very specific words, and their (in)ability to do that influenced the level of their engagement with the app. While cards (whether physical or built into the app) could mitigate this problem, they have a major limitation, as they are limited to a closed vocabulary. We are researching how to design a spelling support that matches the open-endedness of the app itself. First, we are exploring how to incorporate automatic procedures within the app to help scaffold the spelling of new words that children are interested in. Second, we are looking at the ways this support could be provided by people. It appears that researchers acting as guides played a significant role in facilitating children's play in the course of our study. They introduced children to materials, responded to their comments, provided guiding questions and occasionally suggested how to spell specific words. We are currently conducting a study with SB in family settings to determine how well this role could be fulfilled by parents, informed by a learning expert. In the new study, SB acts as a part of a larger human-machine system supporting acquisition of literacy.

It has been shown that analysis of invented spelling offers good predictions of reading development [20]. The log data from SB may have similar affordances. Its capacity to capture early literacy phenomena could become vital for the work of learning experts in the above-mentioned system. Using the data, the experts might be able get a sense of child's interests and specific challenges s/he encounters.

Authorship and learners' ownership of their work were prominent themes manifested during the pilot. The digital medium of a mobile app provides multiple opportunities to further support it. To that end, after the completion of the pilot we implemented the ability for children to save words on the word drawer. With this feature, richer interactions are possible. For example, a child could take a picture associated with the word, record a snippet of his/her voice telling about it, digitally share the word with peers etc. We are currently designing some of these features in our next iterations of SB.

Our hope is not only to support the technical skills of reading and writing, but also to help children develop more positive attitudes towards literacy. For that reason, a good topic for further research is to explore whether playing with SB changes the way children interact with traditional print materials.

CONCLUSION

Constructionist mobile apps for early literacy learning are underrepresented both on the market and in research. To explore the possibilities that such apps can provide, we created the SB app and piloted it with preschool children. We found that children generally engaged with the app. Interaction with the app facilitated learners' sense of agency and ownership of their work which we hope to further reinforce through digital features. The app was a good facilitator of peer learning, evoking a variety of social interactions around literacy activities. The data collected by the mobile devices showed potential to be utilized by learning experts. The results of the pilot support our belief that apps similar to SB have large potential for facilitating literacy learning, both on their own and in combination with other apps. We see space for SB both within classrooms and in home environments. We will continue to further explore and develop this technology.

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