Spelling their Pictures: The Role of Visual Scaffolds in an Authoring App for Young Children's Literacy and Creativity

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ABSTRACT

Children as authors and creators need to be supported at all stages of literacy development. This paper presents Picture-Blocks (PB) – a constructionist mobile app that allows children (ages 5-9) to create personally meaningful digital pictures while exploring spelling and vocabulary concepts in an open-ended manner. In PB, children can spell any number of picture objects (sprites) into existence, that they can use to make a picture composition and share with friends. PB also suggests semantically similar sprites, allowing children to explore related objects and discover new words. We evaluated the app by running an exploratory pilot with 14 children over a two weeks in-the-wild deployment. Qualitative and quantitative examples suggest that our design of the visual scaffolding interactions facilitated (i) high engagement and a sense of authorship via created pictures, (ii) instances of spelling corrections and vocabulary explorations (iii) digitally mediated social interaction and remixing. We present our findings of children's interactions and creations, while discussing implications for designers and developers of literacy technologies.

Author Keywords

constructionism, literacy, multimedia, authoring, spelling, vocabulary, creativity, scaffolding, digital storytelling, pictures, remixing, mobile apps, voice user interfaces

CCS Concepts

• **Applied computing** → **Interactive learning environments**;
• **Human-centered computing** → *Human computer interaction (HCI)*;

INTRODUCTION

Due to their ubiquity, educational apps have the potential to support children at different stages of literacy development [64]. However, in a recent report [67] published by Joan Ganz Cooney Center (2015) on popular literacy apps for children

(ages 0-8), it was shown that around 90% of those apps were targeted for preschool children. A majority of them focused only on basic literacy skills, and were found to be lacking in supporting higher-order literacy skills such as self-expression.

Constructionist approaches to learning emphasize the importance of self-expression and exploration, which have been shown to encourage intrinsic motivation and agency in the support of deeper learning [46, 52]. Computers can be used as a tool for constructionist learning by giving children the freedom to explore and create personally meaningful public objects that are shareable, as opposed to “program[ming] the child” through scripted tasks and answers [46, 47, 27].

Sysoev et al. demonstrated encouraging results on how pre-literate children learned phonetic principles by building words in a constructionist app [65]. For older children, several digital multimedia storytelling tools exist that are grounded in constructionist principles [56, 58]. Most of these studies encourage the role of the child as an active learner, with a focus on meaningful creation rather than consumption. While these examples describe avenues for children's authorship, they either cater to children at pre-literate levels, or to those with sufficient literacy skills to create a complex, text-based story.

For children in early to mid childhood (approx ages 6-8), there appears to be a clear scarcity of literacy apps that provide them with authorship opportunities. This could predominantly be due to children in this age range still developing their literacy skills. They might find it challenging to express themselves through complex reading and writing methods (e.g. digital story authoring tools). This raises an important question:

What avenues can literacy apps provide young children in order to meaningfully express themselves and remain engaged in the learning process?

Exploratory studies using interactive multimedia such as combining drawing and audio [57], have shown promise in becoming tools for self-expression among pre-literate children [41]. The term “multimedia effect” refers to the widely established cognitive benefits of combining words and pictures in the learning process [34]. This symbiosis transcends to affective and motivational benefits, where the attractive and engaging qualities of pictures make them go hand in hand with words [8, 33]. Pictures, in particular, are useful for self-expression in the form of drawings, collages, stickers, etc. The current state of

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Figure 1. PictureBlocks gallery displaying a child's creations.

literacy apps, however, indicate a lack of constructionist uses of pictures towards children's self-expression. Rather, pictures are predominantly used as decorative elements that offer context and may sometimes be interactive, such as flashcards or animations after the completion of a task [67].

These factors motivated us to create PictureBlocks, and run an exploratory pilot to study any unique affordances or limitations of such an approach. In PB, the goal for children is to express themselves through the process of composing digital pictures that are personally meaningful. Designed for children (ages 5-9), PB capitalizes on the appeal and motivation that visual elements have been proven to offer, and uses them to scaffold for engagement in the learning process. Children are provided with a custom keyboard where they can type in words that create objects such as "cat" and "ball" (hereafter referred to as sprites). These sprites can be dragged onto a blank canvas, where they can be manipulated and arranged to form different picture compositions. Once their work is saved, children can also share their creations with friends in the app. Figure 1 displays a gallery with saved picture compositions for an example user. Our contributions are as follows:

- The design and implementation of a visually scaffolded, constructionist literacy app, which demonstrates nuanced opportunities for digital self-expression for children between early to middle childhood.
- Introduction of a creative approach to spelling and vocabulary learning.
- Findings of children's interactions with the app, supported by qualitative and quantitative data.

RELATED WORK

Our work is grounded within the constructionist-inspired framework called the 4 P's of Creative Learning, designed

by Resnick to help develop children as creative thinkers [53]. Resnick defines the 4 P's as follows:

- **Projects:** People learn best when they are actively working on meaningful projects – generating new ideas, designing prototypes, refining iteratively.
- **Peers:** Learning flourishes as a social activity, with people sharing ideas, collaborating on projects, and building on one another's work.
- **Passion:** When people work on projects they care about, they work longer and harder, persist in the face of challenges, and learn more in the process.
- **Play:** Learning involves playful experimentation – trying new things, tinkering with materials, testing boundaries, taking risks, iterating again and again.

We explore how PB relates to these principles in the App Design section, and examine literature on multimodal interactions within children's authoring tools in the section below.

Multimodal Interactions for Children's Self-Expression

Multimodality refers to the use of multiple "modes" of communication and meaning-making that go beyond the written text [30]. In the context of multimedia technology, this can refer to combined uses of images, audio, video, et cetera. Within the framework of children's literacy, this can refer to different forms of expression such as drawings, "cutting-outs", "writings", and collages [29, 19]. For example, young children often talk while they are drawing, with this type of graphic-narrative play offering a richer context to their creations than what either method on its own can usually provide [72, 12].

Such interactions have made their way into prevalent technologies for children, with research showing promising examples of multi-modal digital authoring tools [54, 55] – enabling children to be creators and storytellers, rather than consumers of scripted information [42]. An early example was StoryKit [5], which allowed children (ages 4-11) and their parents to compose stories by juxtaposing photos, audio, text, and drawings. Some recent studies explored the design and integration of a mobile storytelling application within a school curriculum (ages 9-11) [56], and a comic-style approach to digital storytelling (ages 9-10) [58]. All of these tools were collaborative in nature and grounded in constructionist principles. They emphasize on the role of creativity and authorship towards supporting literacy development and even multi-literacies [13], as new forms of multimedia-augmented self-expression emerge.

However, the majority of these tools target children who can create complex, digital stories with accompanying text, often requiring operational reading and writing skills. Even the apps with a broad age range specify that their sweet spot is usually between 8-12 years old, with younger children engaging in more primitive interactions such as drawing instead. For younger children who are pre-literate and not comfortable with writing sentences, such tools may seem challenging and unsuited towards sustained engagement and playful creativity.

Rubegni et al. [57] tried to identify how technology can help pre-literate children (ages 5-6) create multimedia stories without text. They first asked children to use 3 simple iPad apps, designed for drawing, audio recording, and taking pictures and

videos, respectively. In collaboration with peers and teachers, the children used the resulting creations as parts of a larger story. Drawing and audio constituted 89% of the media used, with audio being the most engaging, and drawing posing challenges with imprecision. They recommend authoring apps designed for younger children to focus on shorter stories, as it can be difficult for children of such age to create longer, more articulate stories. They also suggest providing toolsets for combining mixed media, as children found it difficult to switch between apps as a result of cognitive overload.

We noticed a significant gap when studying multimodal interactions and tools for supporting children's self-expression. Children's authoring tools, both in the context of text generation and visual expression seem to exist at two extremes. On one extreme are drawing apps that allow room for little to no text, whereas on the other extreme are elaborate storytelling tools that require sentence construction alongside story layout design. For children (ages 6-8) who are transitioning between these two creative phases, and are mastering simpler language skills such as spelling and vocabulary learning, there are no known avenues for meaningful self-expression both in research and in practice (to the author's knowledge).

In response, we designed PB to (1) allow for the creation of a digital picture (shorter story with a single frame), rather than a complex story with multiple frames, (2) use artist created icons as manipulable sprite objects, rather than drawings (3) include a single area for composing using text, audio and icons – with audio recording embedded into individual sprite icons.

Literacy Research Background

In this section, we examine literature driving spelling and vocabulary learning, and the role of multimedia interactions in supporting and amplifying these skills.

Good spellers often learn new words very quickly, as they have learned to apply spelling strategies such as recognizing sound sequences in words (phonetic), and remembering visual patterns of letter sequences within words (orthographic mapping) [38]. Children acquire these strategies usually by progressing through stages of spelling development, with the last three stages being phonetic to transitional and finally to a correct stage [23]. This is not to say that all misspelled words made before the correct stage are necessarily "wrong". Invented spelling [50, 11] has been encouraged in early literacy practices as it has been linked to phonological awareness. Coupled with appropriate feedback, it has prompted children to apply an analytic approach and eventually correct their spellings to a more conventional form [44].

Given PB's targeted age range (6-8 years), we look at supporting learners in the transitional stage of spelling development. For children in this stage, it is recommended that they pay more attention to the visual sequence of a word, improving their orthographic mapping [62]. Good spellers often display self-regulation, visually processing their word structure to see if it "looks right" and correcting it [31, 25]. Teaching children strategies for checking their spellings has been encouraged, in addition to helping them develop positive attitudes towards spelling by promoting their on-going interests [51].

Apps can be a valuable medium for literacy development as they provide a private space for practice, offer immediate feedback and can be designed for personalized learning experiences, supporting the child as an active participant. [64] Keeping these qualities in mind, with respect to spelling, we designed PB to (1) allow children to think and type words of their choice, (2) encourage children to type a word and then pay attention to its visual appearance to check for correctness, (3) provide auditory feedback for children as they construct a word (to hear if it sounds right).

Various studies have also shown that multimedia interactions, especially pictures with text, have been powerful in improving spelling performance and rates of vocabulary acquisition [45, 60, 73, 68, 20]. Vocabulary size is known to have valuable contributions towards better reading comprehension [16, 1]. Research indicates that vocabulary is best learned with a combination of approaches: direct (teaching individual words), indirect (exposure to rich language – auditory and written), and generative word knowledge (existing knowledge of words that can transfer to newer words) [26].

While we incorporate elements of vocabulary explorations within our app, we do so in a limited fashion as there are no long-form sentences or stories that allow for exposure to rich language immersion. We apply a combination of the aforementioned approaches: (1) direct – new words are presented in isolation, (2) indirect – though the word is presented in isolation, the app reads out its pronunciation and offers additional context by displaying a sprite, and (3) generative word knowledge – we translate this to knowledge of a word's meaning with respect to word associations [7]. Upon displaying a new sprite, the PB app displays three other related sprites to the child. The relations between the sprites reflect real world relationships and are linked to vocabulary acquisition [7, 21].

SpeechBlocks (SB) [65] is an example of a constructionist literacy app which allows children (ages 4-5) to explore phonetic principles in an open-ended way. Children play with letter blocks on the screen by pulling them apart and putting them together, with each sequence being read by a speech synthesizer, including nonsense words. Initial SB studies show potential in terms of playfulness, social learning, and a sense of agency and authorship. Yet, it encountered challenges in sustaining engagement as it had only text-based elements, and researchers had to supplement the app with physical image-based character cards (also used as idea prompts). This further necessitates the need to create a visually scaffolded, constructionist literacy app and study its interactions with children.

THE APP

We apply the lens of constructionism to the overall design of our app. We use a mixed media approach employing visual, voice, and text components, with spelling and vocabulary activities being the literacy focus of the app.

App Design

A constructionist approach to learning encourages child-driven, discovery learning where prior knowledge is used to discover newer knowledge. In addition to exploration, it

states that children learn more effectively if they are expressing themselves by constructing “artifacts”, or objects that are meaningful to them and shareable [46, 47].

Visual Scaffolding

In the context of learning, scaffolding refers to providing supportive interaction to the learner to identify strategies to accomplish a task, and a withdrawal of that support once the task has been learnt [71, 69, 3, 63]. Scaffolds can take many forms, and within PB, we use “visual scaffolds” that utilize the word-picture relationship to enable children’s literacy and creativity. We do so by using the visual scaffolds as a reward to encourage children to spell correctly, and thereby observe their letter sequences. Peer-created pictures can also act as visual scaffolds, allowing the child to discover new words, sprites and object relationships within the creations of others.

In the context of constructionism, our design includes visual scaffolds to aid exploration and self-expression:

1. **Exploration:** Children are allowed to type in any words of their choice into a text keyboard. However, we add a visual scaffold (sprite) to drive the text generation process, to engage and motivate the child. Only upon typing a correctly spelled word, the sprite appears which can then be used by the child. Moreover, we also use sprites as scaffolds to search for other words that exist within the app. Children are presented with word associations such as “cat” related to “dog”, “kitten”, “puppy”, and so forth. When a child has first typed the word “cat”, they are shown sprite objects of the associated words to engage their curiosity, and as prompts for ideas to explore next.
2. **Self-Expression:** Children can use their created sprites to form a picture composition. The overall picture can serve as projects or mini-stories for children, encouraging them to participate in smaller building blocks of the app, such as typing words and discovering sprites.

The Four P’s of Creative Learning

We also analyze the design of PB with respect to Resnick et al.’s four P’s of Creative Learning.

1. **Projects:** For children at the low end of the age range, a project might be the word sprite that they created. For children at the upper end of the age range, a project can be more complex, such as the overall digital picture with multiple word sprites and embedded audio.
2. **Peers:** PB includes a sharing feature, where children can share their created pictures with friends within the app. Friends can edit the received pictures and share them further.
3. **Passion:** PB provides an almost empty canvas, thereby placing control of the app in the hands and minds of the child. Children can type words that are meaningful to them, and eventually design any picture of their choice.
4. **Play:** PB is designed to offer different pathways to play. Children can play with the structure of word spellings, use their curiosity to explore what words exist in the app, stretch their imagination on the blank canvas, and compose and share funny words, sounds and pictures. Children can also hop from word to word, exploring their relations.

Interface and Interaction

Figure 2 displays PictureBlocks and its most salient features. The Keyboard and the Drawer are retractable and can be closed and opened by tapping on their handles respectively. The majority of the app area is the Picture Canvas, where children can add and manipulate sprites to compose a picture. The “cat” and “ball” are sprites that are on the Canvas. The Associations Panel and Audio Panel toggle their visibility when a sprite is tapped or untapped. We describe these features and their design rationales in further detail below.

Figure 2. PictureBlocks and main components in the game area.

Picture Keyboard

The keyboard allows children to type in words of their choice, and thereby, search for sprites to use in their picture. By actively hiding all the sprites that exist within the app, we prompt the child to try to discover the sprites themselves by typing in different words. Moreover, the sprite only appears upon typing a correctly spelled word, in order to motivate the child to type the word correctly. An important aspect of this design is to capture the child’s curiosity by playing with uncertainty, and hiding the rewards they might receive [59].

PB contains a data set of approximately 1,700 words and sprite icons. Upon typing a correctly spelled word that exists within this vocabulary, a hovering sprite icon instantaneously appears on top of the keyboard handle. Figure 3 shows a letter-by-letter play on typing the word “boy” that results in a sprite. While the word is being typed, it is also read aloud by the phone’s speech synthesizer to provide the child with auditory feedback on whether the word they are trying to spell sounds right. When a correctly spelled word is typed but not found in the app’s vocabulary, an emoticon with a sad face appears.

An interesting design question we came across was how to represent homonyms that can be matched to multiple sprites. We included a button that refreshes the sprite to the next one if the current sprite is not the one the child is searching for.

Picture Canvas

The canvas is an empty game area onto which children can drag and drop the sprites they discover using the keyboard. Once the sprites are on the canvas, they can be moved by dragging. Two finger gestures allow actions such as rotating, and scaling the sprites to be smaller or larger. Touching a

Figure 3. Sprite creation using the PictureBlocks custom keyboard.

sprite brings it to the foreground if there is another sprite overlapping with it. These sprites can be manipulated and grouped together to form a composite picture that is left to the child's imagination. The design of the canvas is to provide a space for the child's creative ideas using the sprites – similar to a blank piece of paper used for drawing.

While drawing, in conjunction with writing, has been proven to have a large set of advantages towards literacy [18, 2], young children have primitive drawing skills, making it harder for drawing-based apps to be as visually engaging. Recent findings have also shown that children encountered challenges with precision while using their fingers to draw on the tablet surface [57]. Due to these difficulties, as well as the availability and variety of artist-designed user interface icons, we utilized icons as sprites as opposed to relying on children's drawings.

Upon tapping a sprite, the app reads its word out loud and displays the Associations Panel and Audio Panel to provide the child more options to interact with that sprite. Sprites can be deleted by dragging them to a trash can, which appears upon the drag gesture. Because a picture composition might use duplicate sprites (e.g. a school of fish) – the app allows sprites to be saved and reused without repeatedly re-typing the words. The sprites are saved by dragging them into the drawer and can be subsequently dragged out to the canvas. The drawer also provides backgrounds that can be selected in order to provide ideas or context for the picture compositions.

Word Associations

For each sprite, the associations panel displays other sprites that are semantically related. Word associations are words that arise in one's mind as a reaction to hearing a certain word, due to reasons such as word similarity, contrast, or contiguity [7]. These associations often reflect significant relations between objects and concepts in the real world and are linked to vocabulary acquisition [7, 21].

This feature serves three purposes: (1) to display relationships between sprites that can be explored, (2) to introduce children to words within the app that they do not know about or want to spell, and (3) to prompt the child with new ideas.

Items in the associations panel are interactive buttons. When a word association is tapped, its associations are then displayed, which can then be tapped to display further associations, and so on. For convenience, we refer to the selected sprite as a parent object, and its associations as child objects. Figure 4 demonstrates the steps in exploring the semantic network, starting with “ball” (parent object) and ending at “steak”.

1. After opening the panel for “ball”, the child taps on the button displaying an “egg”. This causes the panel to change.
2. The “egg” is now displayed as the parent object. The previous child objects are replaced with the word associations for egg – eggs, milk, and chicken. Next, the player taps on the “chicken” child button. The panel changes again.
3. “chicken” now becomes the parent, and the child objects are replaced by its word associations – turkey, pork, and steak. The player has now discovered the word “steak”, which can be typed into the keyboard if they want to use it.

Figure 4. Exploration of word associations and the resulting semantic network, starting from the sprite “ball” and ending in “steak”.

Audio Recording

Previous work in children's authoring apps have suggested opportunities for hybrid voice-visual tools to provide pre-literate, younger children with avenues for oral expression [49]. Additionally, this may provide an educator or researcher with more context as listening to their explanations can help understand the ideas on which their picture is based [22, 12].

Taking this into account, our app includes an audio recording feature to record and play children's voices within the picture they are composing. Shown as the Audio Panel in Figure 2, this feature is designed to enable talking while creating in order to help capture voice-visual play and narrative surrounding the picture composition. For each sprite that is on the canvas, the child can tap the audio recording button to add their voice recording to the sprite. The length of each recording is limited

to ten seconds. This audio can then be played back any time they want to hear it by tapping the sprite. The app displays different colored shadows for the sprites in order to highlight those that have an attached audio recording.

Social Sharing

The social sharing feature is designed to allow children to share their picture compositions with friends within the app. Within the app, each child gets a unique player handle. This handle is used as a look-up to find and add friends with whom the pictures can be shared. Children can share a picture by going to their Gallery, which has their saved pictures. Clicking on a picture's share button displays a list of the child's friends, clicking on whom will send them the picture. The received picture indicates the name and avatar of the sending friend, and upon opening, preserves its information allowing the other child to discover words/sprites made by their friend.

Data Considerations

Vocabulary and Sprites

While the keyboard allows for children to type in any word, only certain words have a corresponding sprite. Our goal was to create a corpus of words while (a) maximizing the coverage of words that children within the app's target age range may create, and (b) selecting words that were highly "imageable" and would have corresponding sprites. We refer to this as an imageable vocabulary. Previous research also suggests ties between a word's visual representation and its associations, indicating that the higher the imageability of a word, the stronger its effect on word associations [17]. For the scope of this study, we selected the majority of our vocabulary to be primarily nouns, since they are easier to visualize using static images, as opposed to other parts of speech [10, 4].

Towards these goals, the initial version of the app contained 500 words chosen from the Longman Children's Picture Dictionary [24]. However, during playtesting, several children expressed disappointment at the limited vocabulary. We attempted to expand the corpus by utilizing a larger-scale vocabulary list for children that primarily focused on imageable words but did not find any such corpora.

To address this problem, we created our own imageable vocabulary list. We used the FlatIcon¹ website, which provides icons for 13,500 words. Word-icon pairs were then selected by a researcher by keeping children-friendly words for which there existed a semantically fitting color icon. We note that the FlatIcon icons were preferable to icons retrieved from Google, as they all shared a similar aesthetic. This was an important criterion so as to not negatively impact the appearance of the overall picture composition. The final dataset consists of 1700 words and their corresponding sprites.

Additional vocabulary lists included: (1) the 10,000 most frequent words from Google's Trillion Word Corpus [28], used to signal correctly spelled words that don't have corresponding sprites, and (2) a blacklist of swear words, used to prevent them from being read aloud by the speech synthesizer.

¹<https://www.flaticon.com>

Word Associations

We initially started with the Nelson Norms dataset, the largest available dataset of free association norms, for PB's word associations. This dataset contains association pairs for 5,019 words obtained by interviewing 6,000 participants [40]. However, we found it had insufficient coverage once we increased the size of our vocabulary.

In order to produce associations for any given word, we instead built a model that draws on recent advances in computational linguistics for capturing semantic and contextual relationships between words [37, 48]. For every pair of words within our app's vocabulary, we calculated two word similarity scores using WordNet and GloVe. The final similarity score was a weighted combination of these scores. By using the Nelson Norms as a ground truth evaluation dataset, we determined that a weight ratio of 1:3 (WordNet to GloVe) produced the highest accuracy in terms of predicting the correct association.

WordNet model: We first pre-parsed the WordNet database [36] for every pair of words within our vocabulary. Similarity scores were computed as the shortest distance between each pair of words in the hypernym-hyponym taxonomy graph, which captures type-of relationships such as an "eagle" being a hyponym of "bird".

GloVe model: We trained a model on common crawl data from the web to generate word embeddings. We trained a GloVe model [48], which computes high-dimensional word embeddings by considering the local and global context in which words appear. We then compute the cosine similarity of these word vectors to get a similarity score.

EXPERIMENT

Overview

We first conducted a formal play testing on an initial version of PB with 5 children in a lab environment. All subsequent changes to the app were informally play tested at a museum with child visitors. Observing the interactions in these sessions led to iterations refining the app's design.

We ran an exploratory pilot to study the use of the PB among children in the greater Boston area. This pilot was conducted in the wild [9], with the children being allowed to play with the app in their home environments. This included a pre-study meetup to assign groups and provide the mobile devices, and a post-study meetup to conduct exit interviews.

There were a total of 14 participants, with each child receiving an Android phone with the PB app pre-installed to take home for a duration of 15 days. Since the nature of the study was exploratory, no control group was present. However, we did divide the children into groups to test the social sharing feature. Participating siblings were grouped to as friends within the app, and participants without siblings were grouped together.

Participants

Participants were between the ages of 5 and 9 years old. Though this age group constitutes a range of literacy skills, previous play testing indicated that children of different ages utilized the open-ended nature of PB in different ways. This

wider age range was also in place to support and observe the interactions between siblings using the app.

There were 5 female and 9 male participants – we will refer to them using participant IDs in the range of P1 – P14. Although some participants were from bilingual homes, they were all native English speakers and comfortable with English as a first language. There were three sibling groups within the study. Table 1 displays the age distribution of the participants.

<i>Age (in yrs)</i>	<i>Number of Participants</i>	<i>Male-Female Ratio</i>
5	5	4:1
6	0	–
7	5	3:2
8	2	1:1
9	2	1:1

Table 1. Demographics of participants in this study.

Procedures

Participants and parents were invited for the pre-study meetup after initial recruitment. Each session lasted from around 45 to 90 minutes. There were two researchers present – one to help the parent with consent forms and register on the app, and one to administer a language barrier game (such as Pictionary) among the children. The latter was to help foster a connection between the children prior to the study. Next, the parent and child together selected an avatar for the child within the app. After all the accounts were setup, the children were provided instructions on how to use the app. A picture composition was demonstrated from start to finish, using the app’s features. Finally, the children added each other as friends within the app and took their phones home.

Data and Analysis

While the data from the exit interviews served as qualitative feedback, the app also collected data in the form of logs, tracking every action within the app. We saved the logs, along with children’s picture compositions and audio recordings.

FINDINGS

Overall Results and User Impressions

Children’s use of PB was voluntary, and there were no requirements on the amount of time they had to play. Therefore, we considered the total time spent on the app to be an indicator of engagement and intrinsic motivation, along with factors such as retention, number of sessions, and length of sessions. Each session was counted as the time from when the app was opened to when it was idle or closed.

Over the two week period, children used the app for a median of 15.5 sessions, with each session lasting an average of 12 minutes. This offered some insight into PB’s engagement and the quality of time spent, as a recent report by GameAnalytics found that the top performing children’s games had an average session length of 11 minutes [61]. By adding the individual session lengths together, we also calculated the total median time to be 3 hours and 23 minutes.

We also measured retention, defined as the percentage of players who return to the app after the first session. App industry standards check for continued engagement by measuring retention rates for Day 1 (D1), Day 7 (D7) and so forth. For PB, 80% of children returned to use the app after both D1 and D7, and 50% returned after D14. In comparison, a good D1 retention rate for top-performing games is around 40%, with children’s games reporting only 15%. A direct comparison is difficult due to children being given devices with only PB installed on them, unknown limits on screen-time at home, and the small sample size of the pilot.

The responses to the app were mainly positive, with children’s overall reactions varying from “Good”, “Really great!” to “How did you make this so awesome?”. They particularly liked the large vocabulary of sprites, as well as the open-ended nature (“Well, my favorite part about PB was that it got to find our imagination and helped get a bigger and richer imagination.” - P4, age 8). Dislikes were sometimes feature requests, such as including more words or backgrounds. We also found less retention with older participants. P3 (age 8) said that she started off loving the app but found it less exciting over time as she knew most of the words, and the only thing she felt she could do was to make pictures. During the post-study interview, 10 out of the 14 children reported learning new words or remembering words they had forgotten.

To identify what children perceived the goal of PB as, we asked them how they would describe the app to their friends. Their responses included, in order of youngest to oldest:

- “This app tells you the letters so that you know what letters to type in for the pictures.” (P1, age 5)
- “It’s a very cool app. I can sleep with it in my bed, playing games with it. ... I really loved it. Extra good, because you know, it does lots of fun stuff.” (P13, age 5)
- “I would describe it as fun, yeah it’s really fun... I think PB tries to create your imagination. It’s trying to show us that we can be creative on our own and don’t listen to others creativity. Do your own creativity.” (P4, age 8)

We present some findings from our observations of the data captured during the study, and situate them to support our earlier design framework based on the 4 P’s of Creative Learning.

Finding 1: Children used the app to create a variety of personally meaningful pictures and stories. Several common themes of composition emerged. (Passion & Projects)

Children made a total of 292 pictures. By observing the overall modes of interaction, we identified a variety of common themes, based on which we grouped their picture compositions into seven categories. The collections are listed in Table 2, and examples are shown in Figure 6.

Finding 2: Children used the keyboard to try to discover new sprites, and would try correcting their spellings in order to generate a sprite. (Play & Projects)

Children typed out an assortment of words including correctly spelled words, misspellings, nonsense words, and entire sentences. On average, participants created 104.4 unique sprites.

app. While the goal from the children's perspective was often clearly reflected in the final picture composition, we observed that some younger children spent a lot of time moving the sprites around on the canvas. For them, the focus of the app seemed to be less on the final static picture but rather on enactive playing with sprites using their finger movements, reflective of storytelling using animations.

For example, P13 (age 5) loved superheroes, with every picture including at least one superhero sprite. When observing his replay, we found that P13 would pretend play with the "superman" sprite. Instead of placing it in a particular location, he would spend time flying superman around, and make him huge or tiny to fly him off into the distance.

Finding 4: Children used the associations panel to explore new words and sprites. The real world object relationship between the explored sprites were sometimes visible in the theme of the picture composition. (Play)

Children were able to navigate through the semantic network using the associations panel. On average, the total number of hops by each child in the association network during the pilot was 334.5, with one hop being one tap of a child object. To encourage learning of spelling, the objects in the association panel had to be typed and could not be dragged from the panel. About half of the children (6 of 14) used the associations not just to explore, but to directly inform the typing of their next word. We also created a data visualization called an Association Tree to examine how a child used the associations panel to explore the semantic network. In Figure 7, we view player P7's sea themed picture alongside her association tree starting from the word "crab" and stopping at "pearl".

Figure 7. Picture Composition and Association Tree depicting how the semantic network helped discover new sprites for the sea theme.

Finding 5: Children enjoyed recording their voices and often provided more context to their picture composition. (Play & Projects)

"I liked that you could like make sounds for it...like you could make a cow sound, say something that a cow doesn't say and it would still let you do it." (P8, Age 7) Our audio feature allowed children to record audio for every individual sprite. Qualitative analysis of the audio snippets alongside the final

compositions revealed that most of the recordings were closely tied to the overall picture or theme. The recordings also often provided additional context not found in the composition itself. The audio in Figure 8 perhaps creates a story of an astronaut stranded in a meteor shower.

Figure 8. Sprite audio recordings provide additional context.

Common types of audio recordings are also listed below:

- Musical recordings: singing songs, sentences, opera voices
- Silly sounds: many children loved making silly sounds and would laugh at themselves when replaying it afterwards
- Sprite sounds: this very common play among several children, e.g. animal noises for animal sprites
- Dialogue: some sprites held "conversations" with others
- Storytelling: a story explaining the picture
- Identity: children would speak about themselves as a character, or their in-game avatar
- Social interaction: siblings and even parents would leave recordings communicating with each other

Finding 6: Children shared pictures beyond their siblings and familiar friends. Shared pictures also presented signs of ownership and remixing. (Peers)

Figure 9. Example of remixing a shared picture between two friends. Notice the creative use of pants to add a body.

There were 241 total shared pictures. While the majority of shares (57.3%) were between siblings and the one pair of

children who were friends before the pilot, a sizable fraction (42.7%) were actually between children who didn't know each other before the study or had never even met. Older children with younger siblings showed more sustained engagement in PB than those who didn't have participating siblings. There were also several instances of remixing within the data, where a picture received from a friend was modified by the player into their own version. Figure 9 illustrates one such example between P1 (age 5) and P7 (age 5). This creative appropriation has been demonstrated to be a positive outcome in successful applications for children, and has been shown to act as a pathway for learning [6, 39, 15].

DISCUSSION

Children of different ages used PB in distinct ways. For example, the youngest children (ages 5-6) used the canvas for enactive play (Finding 3), or tended to make patterns and simple compositions. They often reused a set of favorite objects and needed help exploring new words. The oldest children (ages 8-9) made rich and diverse pictures containing stronger storytelling elements, but wanted more features. The "sweet spot" for children using PB was 6-8 years, with the 5 and 9 year olds supporting our initial assumptions about the extremes that exist in present self-expressive apps. The varying usages also recommend a more adaptive version of PB, in which scaffolds are personalized depending on the child's stage of literacy development. For example, for older children, a version of the app can include more storytelling elements (such as characters, dialogue, and multiple scenes).

Finding 2 demonstrates examples of children self-regulating their misspellings in order to get the sprite to pop up. This supports our use of the sprite as a scaffold for exploration. This self-correcting quality has been seen among good spellers, and has been functionally linked to improved spelling performance and better memory of previously spelled words [35, 43, 70].

However, not all children who checked their spellings managed to correct them. Due to time constraints, we did not provide visual feedback for children's invented spellings. If a child made an invented spelling for a word like "dinosor", we hoped to show a faded sprite that would grow more opaque with corrections, indicating to the child that they were getting closer to the conventional spelling. Guided invented spelling has been recommended [14, 44] and we believe it would have improved the effectiveness of the visual scaffold and resulted in more self-correction attempts. In accordance with the literature on scaffolding [32, 63], we can introduce this faded sprite when children encounter trouble with spelling, but only after they have tried to spell the word unassisted. Once the child learns how to spell the word, the faded scaffold can be removed. Explicit instruction on spelling correction strategies are also encouraged [51], and can be included.

To ensure that our content was child-friendly, we manually curated the datasets of words, sprites, and associations. Edge cases can be non-obvious and hard to automatically filter out. For instance, "pot" was matched with a grass sprite, due to "pot" being a colloquial term for cannabis. We also had to search for racial and gender diversity within icons, and decide on whether to include violent sprites such as guns. We

Figure 10. Classroom concept: Solar System, P3 (age 8).

believe this highlights a broader opportunity and need for the design-education-tech space to create trustworthy datasets and guidelines for data design in children's technology. A good place to start would be the creation of an open sourced tool where artists can contribute icon packs, and educators can curate them for child-friendliness.

With the next iteration, a larger, longitudinal study will allow for more diverse participants, and help us evaluate any long term effects on children's engagement and quantifiable literacy outcomes. We would also like to investigate newer features, such as expanding the vocabulary set to include actionable verbs. As one of our users (P4, age 8) said, including a math keyboard and adding the number '123' next to 'cows' should make 123 cows, because "that would be so much fun".

It would also be worth investigating the use of such an app embedded within a classroom curriculum, especially since we already began to see examples of science, math, and history concepts within children's pictures – such as the depiction of the solar system in Figure 10. A school or classroom setting may also help us examine the far reaching effects of the sharing network, if any, and could provide ideas for peer scaffolding.

Despite parents not being given any explicit instructions to participate in their child's app interactions, we observed that parents and even non-participating siblings interacted with the app. Some parents helped younger children spell and discover new sprites. Sometimes, the whole family recorded their voices pretending to be different characters. These interactions are encouraging given that parent involvement in educational apps has been linked to empowering them in their child's learning process [66]. We hope that extending the PB app to allow for more family collaboration and feedback will lead to more personalized creative learning experiences for children.

CONCLUSION

Literacy apps for children offer unique opportunities for a diversity of interactions, explorations, and self-expression at every stage of a child's development. In situating our work in constructionist principles, we found that there was a gap in the range of self-expressive, literacy apps for children aged between 5-9 years. As creators, children seem to be grouped into either simple artists or elaborate storytellers.

PictureBlocks attempts to address children transitioning between these stages, with its design aimed to explore more nuanced forms of engagement, learning, and authoring potential. In our pilot study, children appeared engaged with the app's features and demonstrated a wide range of creative expression while engaging in literacy activities.

SELECTION AND PARTICIPATION OF CHILDREN

Our university's IRB approved our research. We recruited participants through parent self-selection using study flyers, email, and parent Facebook groups across the greater Boston area. During the pre-study meetup, we explained our study and that children's interactions would be recorded and used solely by the researchers. If the children agreed to take part, their parents signed consent forms with explicit consent for recording and sharing children's data. Researchers demonstrated how to use the app. For the friend sharing feature, siblings were grouped together and participants without siblings were grouped together. During the study, we reviewed and verified no inappropriate audio recordings were shared. All data was stored in secure cloud-based storage. Our app's design involved ethical data considerations to ensure child-friendly vocabulary and icon datasets.

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