

Designing Tangible ABCs: Fröbel's Sticks and Rings for the 21st Century

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ABSTRACT

In this paper we discuss why and how we combined the advantages of digital technology with physical manipulatives to scaffold children's learning of letter shapes, names, and sounds. Tangible interactions have been shown to lead to greater learning gains than traditional instruction in several contexts and subject matter. Yet most children are learning their ABCs the same way as they were taught more than a hundred years ago. If there was an engaging, interactive, hands-on alternative to learn the ABCs, what would it look like? To answer that question, we embarked on a design-based research journey based on continued user evaluations and redesign cycles informed by quantitative and qualitative assessments. Inspired by Fröbel and Montessori manipulatives, we discuss the design tradeoffs faced as playful learning goals balanced against constraints including healthy screen time limitations, fine motor control, competing attention targets, and choking hazards.

CCS CONCEPTS

- **Applied computing** → **Interactive learning environments**;
- **Human-centered computing** → *User studies*.

KEYWORDS

design-based research; tangible interaction; interface design; letter recognition; alphabetic principle

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1 INTRODUCTION

Children's letter knowledge is the foundation of literacy. The alphabetic principle is the understanding that there are systematic and prescriptive relationships between written letters and spoken sounds. Given its importance as the first step towards academic achievement and attainment, neuroscientist Dehaene [17] recommended that for young children "all teaching efforts should be initially focused on a single goal, the grasp of the alphabetic principle." The majority of children worldwide are learning their ABCs the same way as they were taught more than a hundred years ago,

despite significant research that has furthered our understanding of how children learn their letters, and despite radical technological advancements. Instead of alphabet books, we have alphabet eBooks and hundreds of apps that aim to replicate the format of traditional alphabet books. Yet digital enhancements of traditional teaching methods do not always offer the same learning potential as the medium changes. Our work aims to adapt the principles of physical manipulatives with a proven track record of improving children's learning shapes and names of letters as tangible interfaces.

This paper chronicles our process of developing a new tangible application for tablets and mobile phones designed to help children learn to recognize letters by their shape and name, learn to form these letters, and pair their shape with the letter sound. Drawing inspiration from Fröbel and from observations of children playing with these manipulatives, following the tenets of design-based research (DBR) methodology [15, 41], we prototyped, evaluated, re-designed, and re-evaluated a letter game for children three through five years old. In this section we begin with a brief review of previous research and existing ways of teaching that inspired us. The "Implementation" section focuses on how our cross-disciplinary team evolved the initial design through sequential iterations of evaluation and development, combining quantitative and qualitative methodologies, concluding with our current future directions. Contributions of this research are aimed at both the practical level as well as the theoretical: for the former, the lessons learned as we implement 19th century manipulatives as a tangible interface to scaffold children's letter learning are adding to the literature towards understanding the characteristics that make tangible interfaces successful. And by sharing our steps as we implemented the DBR methodology as an international collaboration we hope to provide a template for developing educational applications that balance engagement and learning, bringing together innovative research and cutting-edge technologies.

Recognizing and identifying alphabetic graphemes, the smallest unit of a writing system of language, is needed to begin to read independently and with fluency. Cultural differences exist as to whether letter names or sounds are first taught to children at home and in classrooms, yet in the United States visual identification of a letter by name is emphasized before letter sounds and phonological awareness [19]. Hence, letter naming facility of young children is an excellent predictor—if not the best predictor—of reading success and achievement through to the 7th grade and beyond [6, 40] in the United States. And learning letter names requires first developing a familiarity with letter forms, in particular, attuning towards distinctive features of letters to begin to differentiate between similarly-shaped letters [10].

Visual perception of a letter from a novice reader differs from that of experts in their speed at noticing the salient or distinctive areas of letters [10]. It is particularly challenging for younger children

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Figure 1: Sides: Children composing letter “M” and letter “P” using with the Tangible ABCs app on the Osmo platform. Notice the red Osmo mirror reflector and white iPad base. Middle: some of the letters and objects that may be constructed using our sticks and rings.

to reach the conclusion that differences in orientation of similar component marks lead to different letter identification—for example, differentiating between “m” and “w”, or between “p”, “d”, “q”, and “b.” Understanding these differences in orientation is suggested by Dehaene [17] as the main reason why Maria Montessori’s letter learning method of tracing sandpaper letters with a fingertip has been proven to have a positive effects on the reading skills of young children [7, 30]. In Montessori’s method, children learn their letters by breaking down each letter into its sequential strokes, and by experiencing the letter itself through touch, tracing its shape in sandpaper outlines. Today, many digital apps aim to replicate Montessori’s manipulatives (such as [2, 3]) yet the sensory input, the actual manipulation of the object, may be more important to the learning process than the motion. A study comparing learning letter formation through the Montessori sandpaper letters, or by visualizing the sequential construction of a letter on a computer screen, found that the learning gains were only detected in the group who experienced the sensorimotor “act of exploring the letter in itself” [8].

Manipulatives, physical objects such as these sandpaper letter shapes that support children’s learning, are common across cultures and have been integrated into early childhood education through the efforts of first Fröbel, and later Montessori. Each of these pioneers developed a curriculum of structured activities based on modular, aesthetically-simple, developmentally-appropriate manipulatives, that emphasize the importance of involving the child’s senses in the exploration. While Montessori’s curriculum activities and manipulatives focused on constrained, puzzle-like designs that encourage the acquisition of abstract concepts, Fröbel’s emphasize open-ended experimentation and promote construction of natural and man-made forms [43].

Friedrich Fröbel’s gifts, developed for the original kindergarten, are geometrical pieces that allow children to explore formation of complex shapes, patterns and relationships. Fröbel defined a set of gifts—most of them wooden—and named them in the order he recommended presenting them to the child: first gift, second gift, etc. The eighth gift of stick laying advances the child’s progression

in Fröbel’s determined path “inexorably toward ever greater abstraction,” in this case, towards children’s first exercises in letter formation and basic arithmetic [12]. This stick laying gift was composed by groups of wooded sticks in one inch increments (1”, 2”, 3”, 4” and 5”) “like wood matches without the tips” [12]. As forming letters in the Roman alphabet requires more than just vertical and horizontal lines, Fröbel’s followers devised the practical addition of the ninth gift: ring laying composed originally by steel wire rings (1”, 1.5” and 2” in diameter) as well as half- and quarter-circle arcs.

During the past twenty years researchers have sought to merge Fröbel’s and Montessori’s manipulatives with digital technologies, combining the potential benefits of the latter with hands-on learning activities. For instance, digital manipulatives seek to engage children in different types of thinking and develop novel interaction patterns [35, 39, 43] by inserting the technology within the manipulatives themselves. In contrast, tangible interfaces are those that use a variety of physical objects and surfaces as means of manipulating and representing digital information [11, 28]. Another difference is that tangible interfaces are communicating with a computing device, while digital manipulatives may not require this connection.

“Numerous tangible learning environments have been developed” [25], yet despite the intuitive appeal and extraordinary potential of using our bodies and physical artifacts to interact with digital systems [28], tangible learning environments do not always lead to positive learning outcomes [26, 35]. Interactions with manipulatives are modulated by complex interactions between the manipulative itself, the subject matter, the learners’ ability, goals and expectations, culture, and context, including how these manipulatives are introduced [26, 35]. Commercial products with tangible interactions have to be designed carefully given less supervision, greater degree of children’s independent play, shorter engagement time, and greater variety of distractions than at school (pre/kindergarten and preschool) settings—similar to tangible museum installations [25].

Tangible interfaces link to a computing device and increasingly these devices are tablets and smartphones. Today, more than 84% households in the United States own one or more smartphones,

and 68% of households own at least one internet-enabled tablet computer [37]. Their portability and accessibility are driving similar prevalence worldwide [42], and touchscreens are particularly appealing to younger children who are not yet ready for keyboard and mouse interactions. Tablet hardware accessories for younger children are prevalent in the marketplace, making commonplace the sight of an infant using these devices in their car-seat, home, preschool and kindergarten, doctors' offices, and playgrounds, among other settings.

Despite the ubiquity of tablets and smartphones, these offer significant challenges to designing educational apps aimed at children. Among common concerns is the risk of any device with an internet connection for exposure to inappropriate content, whether explicitly disturbing, aimed at a different age group, or merely content that would benefit from critical—and limited—consumption such as advertisements. In addition, the amount of screen time by young children has been negatively associated with developmental outcomes [32] and the recommendations by the American Academy of Pediatrics for children three through five years of age is very limited screen time, of at most an hour per day of “high quality” content [16].

On the other hand, tablet interventions focusing on developing literacy in preschool and kindergarten settings have been shown to increase motivation, confidence and concentration of young children, as well as fostering student engagement in the content [9, 13, 18, 22]. Among reasons for these positive effects are touchscreen interfaces of tablet and mobile phones, and discoverable application designs, which make it easy to understand for pre-readers, and less intimidating to young children [22, 31, 36]. However, interactive animations presented in eBooks and online alphabet-focused apps may hinder letter learning if they distract children by shifting their focus away from the letters [20]. And current tangible applications for learning letters do not focus on teaching letter formation, instead providing children with letter-shaped pieces or lettered blocks with which to stamp or assemble words and experiment with phonics [1, 5, 11, 21].

2 IMPLEMENTATION

Design-based research (DBR) [15, 41] is a systematic methodology aimed at developing educational theories and products through iterative analysis, design, development, and implementation. The development of our playful learning tangible game for learning letter shapes and names is guided by DBR's five principles, that projects must be Pragmatic, Grounded, Iterative, Integrative, and Contextual [41]. DBR projects must be centered in solving a real-world situation (pragmatic), draw from theory and context to understand the situation (grounded), iterative and flexible in evolving through constant assessment and evaluations of how well a proposed solution addresses the situation, integrate a variety of disciplinary research methods including quantitative and qualitative assessments, and lastly, contextualized to the setting where the research is conducted and the solution implemented [15, 41].

Thus far we have reviewed research and evaluations supporting the development of a tangible interface for an application on tablet and smartphones aimed at helping children three through five years of age understand letter formation and learn letter names. In this

section, we discuss the steps in our DBR process conducted to explore and evaluate ideas and prototypes, refining both the software and hardware at every step of the way. The initial explorations were conducted through observation sessions in California, following a weekly design-test-redesign cycle. Once the Alpha app was built, we conducted a two-week-long alpha test in homes across the United States, assessed through both quantitative and qualitative methods, followed by a period of intense redesign. At present we are developing the app for the next evaluation: an in-home beta test, which will be assessed and followed by another design cycle before the app is considered a candidate for release.

We chose to develop on the Osmo platform [4], this tangible interface system is used in over 30,000 classrooms and a million households worldwide in conjunction with an iPad, iPhone, or Fire tablet. Osmo uses proprietary “Reflective AI” technology such that the device detects game pieces placed in front of it in real-time (see Figure 1). This is achieved by placing an angled, down-facing mirror on top of the front-facing camera of the device (red reflector in Figure 1), and setting the tablet on a specialized base. Osmo's computer vision models allow the app to understand what is presented in front of the device and react according to game-specific rules, augmenting the experience with visual and audio feedback. Osmo has released fifteen different games aimed at children five through ten years old, with varying degrees of explicit educational aims and costs. Several games can be accessed for free once the \$20 base is purchased, educational games cover subject matter ranging from spelling, elementary mathematics, drawing, geo-spatial manipulation, and computational thinking fundamentals [4, 27]. However, until now there has not been a product developed on the Osmo platform for learning the alphabet nor a focus on a younger age range.

Traditional alphabet books highlight one letter per page presented next to a depiction of a word that begin with the letter (eg: “Z is for zebra”). Yet research has shown that even “rather plain pictures” when presented next to a letter shape will attract the child's attention away from the letter and may interfere with their learning of the letter shapes or sound [10]. Children are very familiar and enjoy this presentation pattern of having a letter and a fun, known object or animal whose name begins with that letter next to the letter. Based on Both-de Vries and Bus (2014) paper, we decided that letter shapes could be more memorable if the letter and image were presented sequentially in time, rather than sharing the same “page.” That is, we wanted to explore if children's enjoyment would remain if the letter and object did not share the space, but were instead constructed one after the other. We also wondered whether the enjoyment of recognizing a fun object or animal that began with the letter would be diminished given the limits of the sticks and rings as a representational system.

2.1 Observations: First Phase

Inspired by the use of Fröbel's sticks and rings to teach letter formation, observation sessions were scheduled for children to play with the sticks and rings, making letters and patterns. The activities were framed as no-fail creative activity [14], where children could choose to replicate the examples provided or compose their own

constructions. The eventual goal is to provide detailed and engaging feedback to promote the child's learning, yet this first phase was focused on exploration. The object of these initial observations was to evaluate materials and assess different concept ideas for their potential inclusion in the educational app. No actual tablets or smartphones were used to interact, merely as occasional props.

2.2 Observations: Methods

Fifty children were recruited to participate in these, spread over a period of two months. Each session was thirty minutes long on average, and took place in either the participants' homes, our offices, or a local preschool in California. All of the observed children were between three- and five- years of age and came from middle-class backgrounds. Upon arrival, parents reviewed and signed a consent form and NDA. Each session consisted of a single child placing the sticks and rings onto a silicone or paper mat on top of a table, while their parents and the researcher sat nearby. Sessions were unobtrusively videotaped through a tripod camera so that they could be reviewed later.

At the beginning of each session, the researcher explained the goals of the session: for the child to use the sticks and rings to construct several letters, and for each letter to also construct an object that started with that same letter. Participants were provided with 38 pieces comprised of different length sticks and rings, as well as a set of images of letters and objects (that started with that letter) composed using the sticks and rings provided (see Figure 1). Example objects that could be made with the sticks and rings included a boat, flower, ice-cream, and butterfly, among others. The rings pieces included large half-circles, medium half-circles, arcs equivalent to a third of the medium circle, small complete circle rings, and half-ovals. The sticks pieces were six 4" sticks and eight 2" sticks. Children freely decided when to stop the sessions, skip a letter or an object in favor of seeing what came next. Letters and objects were randomly presented. At the end of each session, parents were interviewed briefly about their thoughts on the experience and the concept their child played.

2.3 Observations: Findings

Observation sessions ran during several months, with notable differences in the setup after the first week. The first week we displayed ideas on a laptop screen and had children work on a silicon mat using wooden manipulatives much like Fröbel's. Aiming for a closer simulation to the final experience, we quickly moved towards printed paper pages for displaying idea examples and had children construct their letters on top of a paper mat. For verisimilitude with the Osmo platform interactions, the paper pages were vertically held up onto the Osmo base (right image, Figure 2). In those first few sessions we also learned that wooden manipulatives were too fragile for unsupervised play sessions given the natural propensity of young children to suck, chew on, bend, smash and otherwise explore the limits of the material properties of the manipulatives.

During these observation sessions we noticed certain similar behaviors in the younger children (those between three and four years old) that educators and parents will find very familiar. When asked to construct objects, these children tried to follow the example in 3D—that is, rather than placing the sticks and rings flat on

the table on top of the mat as they had done for the letter, to make a Tree the child would hold the two sticks for the trunk vertically on one hand and attempt to build the canopy with the other. Other examples include construction of the letter "S" would quickly devolve into squiggly snake with too many arc-segments. In addition, younger children reacted strongly to letters that could be found in their name, and found unexpectedly challenging the construction of letters with diagonal lines such as "N" or "Y." Younger children would, at times, flip the letter being constructed as if it was mirrored from the example shown (leftmost image in Figure 2), and they would not, or could not, recognize that the flipped letters they formed did not match the letter example presented on screen. In contrast, older children wanted to show off and preserve their object creations. And all children sooner or later were interested in constructing objects from their own imagination that started with the letter, rather than following the examples suggested by the set of activities.

2.4 Implementing Observation Findings in Game Design

Given the experience, we moved away from wood and towards colorful plastic implementations of Fröbel's sticks and rings that would be both durable and washable. We tested a wide array of plastic sticks and rings during the observation sessions, varying the flexibility and focusing on children's comments and expressions that indicated the child enjoyed playing with them. From jelly-like pieces that delivered the fun yet did not maintain their shape to construct recognizable letters, to harder plastics that broke when bent. Finally, we settled on a food grade silicone implementation for the sticks and rings as a balance between fun "bendiness," stable shape, and safety. Different color combinations of the sticks and rings were explored as well, with choices driven by the confidence with which the Osmo vision system could differentiate between them.

The observation sessions also provided ample feedback about the type of objects and figures children were interested in replicating using the stick and rings, and the relative difficulties of various compositions. Children enjoyed making letters and constructing objects in the short sessions, yet as we began discussing the process of building the app itself, we were concerned that they perhaps would not have a strong enough motivation to return to the game after playing it or to keep playing it once the letter construction became challenging. Prompted by the expressed desire to save and share their creations, an idea emerged of capturing the table top art as a shareable image through the camera. A "meta-game" was designed where children's images of completed letter-object pairs would be captured and stored in a shareable postcard image. Activities became broken into postcard-sized groups of three letters, with their three corresponding doodles, set in a graphical postcard that matched the theme. Postcards would be delivered to the child featuring the example letter constructions as images within, yet they would be saved with the child's doodle creations for sharing and reviewing. The squiggly snakes that were created during the observation sessions for the letter "S" inspired us to animate the doodle creations in the postcard in funny and joyful ways.



Figure 2: Images from the Initial Observation sessions. Left, letters deemed ‘correct’ by the younger children. Middle: child composing image of a flower. Right, paper example in vertical position to simulate iPad in Osmo stand showing a anthropomorphic figure, with child’s composition below.

Interaction patterns in the Alpha app starts with the child receiving a randomly selected graphical postcard that includes three stick and rings letters. For example, a postcard with a drawing of an ocean would have the letter “F” and “J” underwater and the letter “B” floating at the waterline. The child would choose the order of the letters to compose, perhaps choosing to make the letter “F” first. Once completed the child is verbally requested to construct the “fish” doodle (“I know a word starting with F: fish! Could you make a fish using the sticks and rings?”). The image of the child’s created fish is saved onto the postcard in the position where the letter was, with a possibility of editing the design and retaking the photo. Next would come the letter “J” for “jellyfish,” and “B” for “boat.” The completed postcard is saved in a gallery, with the animated fish, jellyfish, and boat swaying in the current.

Aiming to provide educational content for older children, both lowercase and uppercase letters were implemented. In addition, given greater likelihood of unsupervised play, Mo the monster was added as an on-screen embodied character whose interactions go beyond merely providing instructions. Previous research has shown that emotive characters directly impact learning outcomes, as well as feelings of being supported [11, 29, 33, 34]. Through Osmo’s “Reflective AI” technology, Mo comments on the children’s creations providing fun animations, emotive feedback, and guiding play towards the learning objectives. These interactions explicitly foster a parasocial relationship between the child and Mo, which research has shown maximizes opportunities for learning [23, 24, 29] (see Figure 1). To encourage children’s creativity, examples of the possible objects that started with the just-finished letter would be given only if the child tapped the hint light bulb that appeared above the monster host after thirty seconds on inactivity.

The ABC Alpha app was meant to be a proof-of-concept, exploring whether the interaction pattern based on postcards and doodles proved to be sufficiently motivating to the children. As such it was only implemented for some iPad devices and with a small set of nine postcards, thirteen unique letters and fifteen unique doodle construction opportunities. We included more doodles than unique letters as some of the letters children had experienced problems with during the Observation sessions were repeated with different doodle pairings to emphasize the letter construction.

2.5 Alpha Testing: Method

For our second evaluation we selected a geographically-distributed set of fifty volunteer family testers who had appropriate devices, children three- through five years of age, and who owned the Osmo base. Median child age in the Alpha was four years old, yet the range of ages of children that played with the sticks and rings started at two years of age and ended at twelve, as most of the selected families had multiple children who were curious about the experience. Volunteer families did not live in or within a 45 miles radius of any of the four most technically-savvy metropolitan areas in the US, as we were interested in knowing whether the design affordances were easy to understand. No Silicon Valley, Seattle area, New York City area, or Los Angeles area families were selected. Applications were done online, and families selected were asked to sign an NDA.

Testers received the prototype sticks and ring pieces in the mail; as compensation they were guaranteed free release versions of the final product if and when it was commercially released. Testers were provided with a unique link to download the Alpha ABC app, and technical support was provided through email. They agreed to play at least for half-an-hour during two weeks, and to complete an honest post-experience questionnaire. Moreover, they gave permission to have us analyze their anonymized play data from the Alpha ABC app. Regarding demographics, the families considered themselves to be middle-class, 20.41% were homeschooling their children, and a further 22.43% had at least one household member working as a teacher.

2.6 Alpha Testing: Results

In terms of analytics of play data, the median number of postcards started per device was 5. The median number of letters completed per device was 10, and the median number of doodles completed was 8—yet the averages for both were higher, at 12.91 and 16.55 respectively. The fact that the average was higher than the median indicates that a few of the Alpha tester families completed many more letters and doodles than the median.

Quantitative results from the survey based on a five-point Likert scale were very positive: 83% of the families reported they would be

"Very Satisfied" or "Extremely Satisfied" with the Alpha game should it be produced commercially, and 75% thought it was "Very Educational" or "Extremely Educational" in its current implementation—even though the Alpha app did not assess the correctness of the letter constructions. The monster host was very popular with the children, with 36% finding him "Extremely enjoyable," and 36% rating him "Very enjoyable," the two highest scores in our 5-point Likert scale. The nuances and refinements of our introduction to the activity, learned during the observation sessions were appreciated as well: when asked "for your children, understanding how to play the ABC concept Alpha game was..." 46% of families ranked it at the easiest point in the scale ("Very easy") and 42% ranked it as "Easy."

The material look and feel of the prototype stick and rings were overwhelming enjoyed, with 71% reporting that their family "Loved them" and 19% "Liked them" (top two options in a five point Likert-scale). We were concerned that the pieces would be too small for younger children to manipulate easily given their fine-motor control, yet only one family reported a desire for them to be wider. Moreover, 57% of the families reported that their children played with the sticks and rings without the iPad app several times during the testing period. One parent wrote: "Even after I took the screen away my 4- and 5-year old were still making things with them!" This result harks back to the qualities of playful learning of these tried-and-tested manipulatives, and reassures us of the value of our contribution towards healthy play given the limitations on screen time recommended for children in the target age range.

In terms of qualitative responses to the survey to the freeform questions, Alpha tester families' number one request was the development of many more postcards and doodles. Reports of engagement were positive, with children playing independently and asking to play across several days. And the explanation as to why the letters completed median was higher than the doodle completed median became apparent when reading the free-form responses: children did not mind repeating what we considered to be the less fun construction of letters, as long as the reward doodle was seen as fun and unique. The moment the doodle repeated or was not seen as fun, children were no longer interested in completing a postcard.

2.7 From Alpha to Beta and Beyond

The results from the Alpha of the postcard interaction pattern and Monster host were very encouraging. Our next steps are clear: we will redesign the ABC app to incorporate results from the Alpha test, and plan for two separate Beta tests to validate our design decisions.

The first beta test will take place in two schools with large linguistic diversity that qualify for "Title 1" funding, that is, where at least 40% of their students come from low-income families who are considered to be living at or near poverty. These children may benefit more from assistance in developing literacy skills than the middle-class cohort, and their interactions may differ in ways we have not addressed thus far in our prototype development. The second beta test is a large geographically distributed in-home Beta test drawing from a comparable audience as our Alpha test.

In terms of product development, we are exploring a few different directions concurrently by prototyping, testing, redesigning, and

repeating the process until we reach a satisfactory solution. The first of these is the ability of having the app verify the correctness of the constructed letters. We are evaluating different alternatives to deliver the feedback on letter formation - with respect to the content of the message, as well as the delivery mechanism: is it the Monster host that is confused by the imperfectly formed letter, or is it an unseen judge? A second dimension we would like to explore are ways to capture the evolution of a child's letter construction over time. While parents and teachers would appreciate this feature, it could also be used to fine-tune the interaction in ways that prioritize learning letter shapes while maintaining the fun, creative doodles. This qualitative assessment of learning through the app could be validated other assessment metrics during the planned Beta Test.

Thirdly, the wide-range of abilities and knowledge of children in the target age-range of three through five years old has prompted us to consider making the application responsive or adaptive to the children's abilities. Younger children likely know fewer letters, and would have a more challenging time with the precision and fine motor control required to form complex object shapes using our sticks and rings. The scaffolding [38] needed by younger children to learn the process of constructing a letter should gradually fade as their competency increases. And a child who knows how to write in upper and lower case letters would appreciate a competency challenge suited to their ability—whether it is based on object complexity, timing, phonological awareness, or other possibilities.

Expanding the number of doodles and postcards was the Alpha testers' main request, yet it may not contribute directly to learning the letter names, recognizing or constructing their shape. This fourth dimension is focused on evaluating the possibility of whether the additional doodles indirectly contribute to the children's learning by increasing the amount of time played. A fifth direction we are exploring is the possibility of leveraging the postcard metaphor further by having children address their postcards to family recipients and sign their own name, constructing each letter one by one.

3 CONCLUSION

In this paper we have discussed the theoretical background and inspiration for the design of a new tangible application for tablets and mobile phones designed to help children learn to recognize letters by their shape and name. While the evaluations of the success of the Tangible ABCs at teaching letters are not yet completed, we offers a detailed look into the process of applying design-based research principles through sequential iterations of testing and development that combine qualitative and quantitative assessment methods. Contributions of this research are aimed at both the practical level as well as the theoretical: for the former, the lessons learned as we implement 19th century manipulatives as a tangible interface to scaffold children's letter learning are adding to the literature towards understanding the characteristics that make tangible interfaces successful. And by sharing our steps as we implemented the DBR methodology as an international collaboration we hope to provides a template for developing educational applications that balance engagement and learning, bringing together innovative research and cutting-edge technologies.

4 SELECTION AND PARTICIPATION OF CHILDREN

Parents of children ages three through five years old volunteered online to participate in our research. Observation sessions of approx. 30 mins, took place in homes, preschool, or offices. Parents signed consent form, children gave verbal consent, including for anonymous research uses of videotape and images. Parent was present in room with child, and children freely decided when to stop the sessions or change activities. Compensation was a small Amazon gift card, as well as one educational toy for the child pre-approved by the parents. For in-home Alpha Test parents signed consent form and reported if children did not wish to participate. Permission was obtained for anonymous play data analysis and sharing of survey responses. At any time, children could decide to interrupt their participation without negative consequences. Free release versions of the final product when it would be commercially released were offered as compensation.

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REFERENCES

- [1] [n. d.]. Marbotic Smart Letters. <http://www.marbotic.fr/smart-letters/>. (Accessed on 01/23/2019).
- [2] [n. d.]. Mobile Montessori Quality Educational Apps For Kids! <https://www.mobilemontessori.org/>. (Accessed on 03/26/2019).
- [3] [n. d.]. Montessorium: Learning is a Lifestyle. <https://montessorium.com/>. (Accessed on 03/26/2019).
- [4] [n. d.]. Osmo—Award-Winning Educational Games System for iPad. <https://playosmo.com/>. (Accessed on 01/23/2019).
- [5] [n. d.]. Tiggly Words Learning System for Tablets. <https://tiggly.com/tiggly-words-learning-system>. (Accessed on 01/23/2019).
- [6] Marilyn Jager Adams. 1994. *Beginning to read: Thinking and learning about print*. MIT press.
- [7] Florence Bara, Edouard Gentaz, and Pascale Colé. 2007. Haptics in learning to read with children from low socio-economic status families. *British Journal of Developmental Psychology* 25, 4 (2007), 643–663.
- [8] Florence Bara, Edouard Gentaz, Pascale Colé, and Liliane Sprenger-Charolles. 2004. The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle. *Cognitive development* 19, 3 (2004), 433–449.
- [9] Beth Beschorner and Amy C Hutchison. 2013. iPads as a literacy teaching tool in early childhood. *International Journal of Education in Mathematics, Science and Technology* 1, 1 (2013), 16.
- [10] Anna C Both-de Vries and Adriana G Bus. 2014. Visual processing of pictures and letters in alphabet books and the implications for letter learning. *Contemporary Educational Psychology* 39, 2 (2014), 156–163.
- [11] Mindy Brooks and Emily Reardon. 2016. Sesame Street, letter blocks, and augmented reality: Increasing engagement and learning. <http://uxpamagazine.org/sesamestreet-letter-blocks-and-augmented-reality/>. (Accessed on 01/23/2019).
- [12] Norman Brosterman and Kiyoshi Togashi. 1997. *Inventing kindergarten*. HN Abrams New York.
- [13] Linda Clarke and Lesley Abbott. 2016. Young pupils', their teacher's and classroom assistants' experiences of iPad use in a Northern Ireland school. *British Journal of Educational Technology* 47, 6 (2016), 1051–1064.
- [14] Michael Cohen, M Hadley, and M Frank. 2011. Young children, apps & iPad. *US Department of Education Ready to Learn Program* 200 (2011), 5–10.
- [15] Design-Based Research Collective. 2003. Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher* 32, 1 (2003), 5–8.
- [16] ON COMMUNICATIONS COUNCIL et al. 2016. Media and young minds. *Pediatrics* 138, 5 (2016).
- [17] Stanislas Dehaene. 2009. *Reading in the brain: The new science of how we read*. Penguin.
- [18] E Dobler. 2012. Using iPads to promote literacy in the primary grades. *Reading Today* 29, 3 (2012), 18–19.
- [19] Michelle R Ellefson, Rebecca Treiman, and Brett Kessler. 2009. Learning to label letters by sounds or names: A comparison of England and the United States. *Journal of Experimental Child Psychology* 102, 3 (2009), 323–341.
- [20] Mary Ann Evans, Sarah Nowak, Brittany Burek, and David Willoughby. 2017. The effect of alphabet eBooks and paper books on preschoolers' behavior: An analysis over repeated readings. *Early Childhood Research Quarterly* 40 (2017), 1–12.
- [21] Min Fan, Alissa N Antle, Maureen Hoskyn, Carman Neustaedt, and Emily S Cramer. 2017. Why tangibility matters: A design case study of at-risk children learning to read and spell. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 1805–1816.
- [22] Rosie Flewitt, David Messer, and Natalia Kucirkova. 2015. New directions for early literacy in a digital age: The iPad. *Journal of Early Childhood Literacy* 15, 3 (2015), 289–310.
- [23] James H Gray, Emily Reardon, and Jennifer A Kotler. 2017. Designing for Parasocial Relationships and Learning: Linear Video, Interactive Media, and Artificial Intelligence. In *Proceedings of the 2017 Conference on Interaction Design and Children*. ACM, 227–237.
- [24] Kathy Hirsh-Pasek, Jennifer M Zosh, Roberta Michnick Golinkoff, James H Gray, Michael B Robb, and Jordy Kaufman. 2015. Putting education in the apps: Lessons from the science of learning. *Psychological Science in the Public Interest* 16, 1 (2015), 3–34.
- [25] Michael S Horn. 2018. Tangible Interaction and Cultural Forms: Supporting Learning in Informal Environments. *Journal of the Learning Sciences* (2018), 1–34.
- [26] Michael S Horn, R Jordan Crouser, and Marina U Bers. 2012. Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing* 16, 4 (2012), 379–389.
- [27] Felix Hu, Ariel Zekelman, Michael Horn, and Frances Judd. 2015. Strawbies: explorations in tangible programming. In *Proceedings of the 14th International Conference on Interaction Design and Children*. ACM, 410–413.
- [28] Hiroshi Ishii and Brygg Ullmer. 1997. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human factors in computing systems*. ACM, 234–241.
- [29] Alexis R Lauricella, Alice Ann Howard Gola, and Sandra L Calvert. 2011. Toddlers' learning from socially meaningful video characters. *Media Psychology* 14, 2 (2011), 216–232.
- [30] Angeline Stoll Lillard. 2016. *Montessori: The science behind the genius*. Oxford University Press.
- [31] Julianne Lynch and Terri Redpath. 2014. Smart technologies in early years literacy education: A meta-narrative of paradigmatic tensions in iPad use in an Australian preparatory classroom. *Journal of Early Childhood Literacy* 14, 2 (2014), 147–174.
- [32] Sheri Madigan, Dillon Browne, Nicole Racine, Camille Mori, and Suzanne Tough. 2019. Association between screen time and children's performance on a developmental screening test. *JAMA pediatrics* 173, 3 (2019), 244–250.
- [33] Heidy Maldonado, Jong-Eun Roselyn Lee, Scott Brave, Cliff Nass, Hiroshi Nakajima, Ryota Yamada, Kimihiko Iwamura, and Yasunori Morishima. 2005. We learn better together: enhancing elearning with emotional characters. In *Proceedings of the 2005 conference on Computer support for collaborative learning: learning 2005: the next 10 years!* International Society of the Learning Sciences, 408–417.
- [34] Heidy Maldonado and Clifford Nass. 2007. Emotive characters can make learning more productive and enjoyable: it takes two to learn to tango. *Educational Technology* (2007), 33–38.
- [35] Andrew Manches and Claire O'malley. 2012. Tangibles for learning: a representational analysis of physical manipulation. *Personal and Ubiquitous Computing* 16, 4 (2012), 405–419.
- [36] Michelle M Neumann and David L Neumann. 2014. Touch screen tablets and emergent literacy. *Early Childhood Education Journal* 42, 4 (2014), 231–239.
- [37] Kenneth Olmstead. 2017. A third of Americans live in a household with three or more smartphones. *Pew Research Center* (2017).

- [38] Roy D Pea. 2004. The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *The journal of the learning sciences* 13, 3 (2004), 423–451.
- [39] Mitchel Resnick, Fred Martin, Robert Berg, Rick Borovoy, Vanessa Colella, Kwin Kramer, and Brian Silverman. 1998. Digital manipulatives: new toys to think with. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM Press/Addison-Wesley Publishing Co., 281–287.
- [40] Rebecca Treiman. 2000. The foundations of literacy. *Current Directions in Psychological Science* 9, 3 (2000), 89–92.
- [41] Feng Wang and Michael J Hannafin. 2005. Design-based research and technology-enhanced learning environments. *Educational technology research and development* 53, 4 (2005), 5–23.
- [42] Mark West and Chew Han Ei. 2014. *Reading in the mobile era: A study of mobile reading in developing countries*. UNESCO.
- [43] Oren Zuckerman. 2010. Designing digital objects for learning: Lessons from Froebel and Montessori. *IJART* 3, 1 (2010), 124–135.