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Deaf Children's Engagement with American Sign Language-English Bilingual Storybook Apps

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Abstract

Design features of American Sign Language (ASL)-English bilingual storybook apps on the tablet computers, based on learning research, are intended to facilitate independent and interactive learning of English print literacy and of ASL skill among young learners. In 2013, the Science of Learning Center on Visual Language and Visual Learning introduced the first in a series of storybook apps for the iPad based on literacy and reading research. The current study, employing a sample of signing deaf children examined children's self-motivated engagement with the various design features presented in the earliest of the apps, *The Baobab,* and analyzed the relationships of engagement with ASL skill and age of first exposure to ASL, ASL narrative ability, and grade-appropriate English reading ability. Results indicated a robust level of engagement with the app, and a relationship between app pages specifically targeting reading and early exposure and skill levels in ASL. No evidence of relationships between narrative and vocabulary skills and app reading engagement was found. Topics for future research, and strategies for app improvement are discussed.

The launch of the iPad over a decade ago provided a unique opportunity to promote language and literacy development in deaf and hard-of-hearing children. The touchscreen feature of iPads enabled the seamless integration of American Sign Language (ASL) videos and English text on a single screen, providing users with a rich bilingual, immersive, and interactive environment. Released in 2013, *The Baobab* was the first bilingual storybook app (SBA) designed for emerging readers who rely on a visual language. *The Baobab* is about a curious girl who goes on a search to find the delicious fruit from the Baobab, an ancient tree. This story is told in both ASL and English and includes illustrations. This story is designed for children between 4 and 8 years old and was created by researchers, reading specialists, designers, programmers, and artists working with the National Science Foundation/Xxxx University Science of Learning Center on Visual Language and Visual Learning (VL2; Malzkuhn & Herzig, 2013). Considerable effort went into the design of the SBAs, ensuring that principles of learning based on previous research were employed.

Bilingual Storybook Apps and the Science of Learning

The introduction of the VL2 SBAs was timely, given evolving conceptions of literacy, bilingualism, multimodal practices, and discoveries demonstrating the potential benefits of early exposure to visual languages on subsequent literacy development for children who were deaf. At the time when digital technologies, such as tablet computers, were becoming more ubiquitous and being introduced as multimodal interactive learning tools for children under the age of 8 (Marsh, 2016, 2019; Oakley, et al., 2020), the concept of literacy was also changing. The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2022), summarizes these changes in an international context: "Beyond its conventional concept as a set of reading, writing and counting skills, literacy is now understood as a means of identification, understanding, interpretation, creation, and communication in an increasingly digital, text-mediated, information-rich and fast-changing world."

Kuntze et al. (2014) articulated how a broader definition of literacy might apply to learners of a visual language, such as ASL. The Kuntze et al. model "incorporates components of ASL acquisition, visual engagement, emergent literacy, social mediation of English print, literacy and Deaf culture, and a variety of media (p. 203)" These authors note that visual learners are capable of learning to read without first learning the sound-letter associations commonly (and erroneously) thought to be a prerequisite for learning to read. Additionally, they note that deaf children raised in signing families must learn a second language, as they learn to read. Consistent with the UNESCO definition, Kuntze et al. discuss the idea of "multiple literacies," suggesting that different literacies (English, ASL, cultural, and digital literacies, for example) can be mutually supportive of learning.

Bilingualism and Reading

In recent years, researchers have turned their attention to the cognitive benefits of bilingualism, which is a core design element in the SBAs. Children raised in bilingual families exhibit greater awareness of the prosody of language, stronger cognitive development, and higher reading levels than their peers raised in monolingual families (Allen, 2015; Bialystok et al., 2009; Kovelman et al., 2013; Jasińska & Petitto, 2013, 2014; Petitto, 2009; Snoddon, 2014). The age of first bilingual (e.g., ASL and

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English) language exposure is strongly correlated to deaf and hard-of-hearing children's ability to develop complex reading knowledge (Berens et al., 2013; Jasińska & Petitto, 2013). Early bilingual exposure, preferably before the child starts elementary school, gives rise to higher subsequent levels of literacy.

Dual language exposure enhances metalinguistic knowledge, allowing children to transfer their growing knowledge about language structures across their different languages. The SBAs were developed to promote this metalinguistic knowledge. The apps include complex linguistic structures in both ASL and English, for example, role shifting and using classifiers. Deaf children who gain implicit knowledge of ASL grammatical structures through early exposure and use can transfer this knowledge when learning a second language (Cummins, 1996; Krashen, 1992).

Benefits of Early Exposure to a Visual Language

In addition to the affordances enjoyed by children from bilingual families, both deaf and hearing, and spoken or signed, the experience of early exposure to sign language offers many advantages for deaf children, even those who come from monolingual hearing families who embrace sign language as a means of communication. This early exposure (by six months of age) has been shown to lead to age-level vocabulary growth (Caselli et al., 2021) among deaf children in hearing families. In a longitudinal study (Allen & Morere, 2020), a young deaf child's receptive ASL skill explained their rate of growth in early literacy, even when the hearing/deaf status of their parents was controlled. These findings suggest that it is the acquisition of a visual language that accounts for later literacy development, and not the hearing status of the parent.

Many research studies have explored the relationship between early ASL skill and subsequent linguistic, communicative, cognitive, academic, literacy, and psychosocial development (e.g., Kushalnagar et al., 2020; Mitchiner et al., 2012). Deaf children's fluency in ASL is correlated with their literacy, language, cognitive, and cultural development (Allen & Herzig, 2005; Hoffmeister 2000; Morere & Allen, 2012; Padden & Ramsey, 2000; Prinz & Strong, 1998). The presence of this correlation suggests that educational materials presented in both ASL, and English might facilitate language development in both languages. Morgan (2006) argues that deaf children should be exposed to extended uses of sign language (e.g., stories) to provide them with "opportunities to develop potential cognitive flexibility and metalinguistic abilities in order to facilitate the development of English literacy skills" (p. 338). Baker (2010) emphasized the importance of early exposure to fingerspelling, which facilitates English vocabulary development and thus helps children become better readers. Yet there have been few materials developed for use with young deaf children that capitalize on the potential benefits of bilingual materials that include spoken and print English, ASL, and fingerspelling. The VL2 Apps were developed to help remedy this lack.

Parental Engagement through Shared Reading Experiences

Only 20% of elementary and middle school deaf and hard-of-hearing students reported that their parents read with them (Ewoldt, 1986). Parents' limited sign language skills may be the reason for this. Furthermore, parents may not know how to engage their children appropriately while storytelling by tapping shoulder or maintaining eye gaze to elicit the child's attention (Lartz & Lestina, 1995). Mueller and Hurtig (2010) found that using e-books resulted in more time dedicated to shared reading activities and signed vocabulary acquisition among deaf and hard-of-hearing children and their parents. ASL literacy is a social practice, and it benefits the parents if they can learn ASL as well as read with their child (Snoddon, 2020). There are studies that show that deaf and hard-of-hearing children develop emergent literacy skills through programs that teach the parents how to share books through sign language (Snoddon, 2014). When parents can learn ASL through this SBA, they can then share books with their children and build on their children's literacy experiences.

Top-Down and Bottom-Up Processing

The SBAs employ an approach that entails an interaction between top-down and bottom-up processing (Hyte, 2016). The child's experience with the app begins, in Watch mode with an ASL presentation of the story. This provides a top-level network of meanings for the child that will help facilitate the process of reading. When the child moves from Watch mode to Read mode, the child encounters strings of letters and words comprising a small segment of the story (typically one sentence), which may, at first, hold little meaning. From the Read page the child can begin to parse the sentence into words, and words into letters by tapping on the "active" (hyperlinked) vocabulary to bring up a chained sign-fingerspelled-signed presentation. They can also tap on a play button to see the translation of the entire page into ASL. This also provides training in the idea that the full process of the story is made up of separate sentences. The child can move back and forth to support top-down understanding (Goodman, 1986; Heymsfeld, 1989; Rayner et al., 2002) and bottom-up fingerspelled letters to word.

Research has demonstrated increased reading motivation in children if they are able to listen to the stories being read aloud (Herzig, 2009; Herzig, 2019). The same principle applies to supplying definitions during reading (or, in the case of these apps, in form of signed/fingerspelled words) (Herzig, 2009). Lower-level processes such as rapid word recognition must occur prior to the achievement of reading fluency and high-level comprehension processes (Torgesen, 1986). The more children's lexicons expand, the more they benefit from top-down reading processes that are offered in the design of this VL2 storybook app.

Interactive Engagement and Active Learning

Research suggests that children learn best when they are cognitively engaged. Active learning includes physical activity such as swipes and taps (Hirsh-Pasek, Adamson, et al., 2015, Hirsh-Pasek, Zosh, et al., 2015). In the SBAs, children can swipe the pages during Read mode and tap on words to see signed and fingerspelled equivalents. Additionally, children learn more through contingent interaction than passive TV watching (Roseberry et al., 2014). When swiping or tapping elicits an immediate response (i.e., haptic feedback), children feel in control and thus maintain their focus and continue the interaction (Nielsen, 1994). Using the VL2 storybook app, children can control the pace of the story, the "interactivity principle" (Balci, 2009). This promotes engagement among children.

Concurrent Access to Two Languages

SBAs offer access to both ASL and printed English, allowing the children to flip back and forth between the two languages. Previous research (e.g., Petitto, 2009) on bilingualism has explored differences between a child learning two languages concurrently during the preschool years versus those who have delayed exposure to a second language. Concurrent early exposure to two languages leads to stronger literacy skills.

Equal representation appears to be valuable to bilingual children, enhancing their reading experiences (Martin & Stuart-Smith, 1998; Snoddon, 2008). By looking at the interactive features included in the e-books, three instances of equal language representation include: manual playing of ASL videos, the presence of printed English vocabulary support, and a singular, full-story ASL video (Stone, 2014). This storybook app has met all three interactive features that indicated equal language representation. This storybook app also allows for viewing the story entirely in ASL without reading in English and vice versa. Naturally, children will benefit most in social environments where both English and ASL are used. Thus, the SBAs will not replace ASL-English bilingual education and a family who is also learning ASL but will serve as a valuable supportive bilingual educational tool.

Phonological Processing of Sub-Lexical Elements in Spoken and Visual Modalities

Employing a professional signing ASL storyteller who also possesses expert fingerspelling skills facilitates the child's growing understanding of the separate phonologies associated with both ASL and print-based English. Phonology is not bound to sound, but to the sublexical units of language, spoken, signed, or written. For those who don't have access to sound, spoken language phonological awareness may not be necessary for them to learn to read (Mayberry et al., 2011). Recent research in cognition, neuroscience, and early reading has emphasized the role of visual sign phonology in emergent reading (Allen, 2015; Petitto, et al., 2016). It emerges from the work that shows that babies' brains are "hard-wired" for language, regardless of whether the language comes in through the eyes or through the ears (Petitto, et al., 2016). Hearing is not required for learning, but language is. All languages, including the documented 7,000+ spoken languages and 141 sign languages (Simons & Fennig, 2017), have complex grammars with many universal features such as nouns, verbs, plurals, tenses and so on.

The SBAs are based on recent findings that demonstrate that the mastery of one phonology (visual phonology) can support the acquisition of languages based on different phonologies. A growing number of studies have noted a relationship between ASL phonological awareness and early print literacy skills (Morere & Allen, 2012; Goldin-Meadow & Mayberry, 2001; McQuarrie & Abbott, 2013; Morford et al., 2011). A wealth of scientific evidence shows that children need to develop the phonological level of language organization through sound or visual languages (e.g., Baker et al., 2006; Holowka & Petitto, 2002; Jasińska & Petitto, 2014; Petitto, 2005; Petitto, et al., 2012; Petitto, et al., 2004; Petitto & Marentette, 1991; Petitto, et al., 2000). One can develop visual phonological awareness in sign language through handshape, patterns, movement, and rhythms. This biological process features the segmentation of languages on the hands (Petitto, et al., 2016). Early exposure to ASL develops, in the young deaf child, the ability to segment signs into their component visual phonological units, which, in turn, promote segmental decoding of print (Petitto, et al., 2016). A primary reason that many deaf children who struggle with learning literacy is not because of their lack of auditory input, but to their lack of language experiences and visual phonological awareness (e.g., Baker et al., 2006; Holowka & Petitto, 2002; Jasińska & Petitto, 2013, 2014).

Deaf children do not get the same benefits from patterning, rhyming, and the language play that involves sounds as those who hear. Instead, there are patterns, rhymes, and language play that is distinct in sign language. Through the study of effects of ASL rhyme and rhythm, it shows children's increasing engagement in language play and accurancy in recitation as compared to those who read non-rhyming ASL stories (Holcomb & Wolbers, 2020). The ASL Parent–Child Mother Goose Program for parent-infant program, which teaches oral rhymes, stories, and songs to parents of deaf children, supports visual attention, phonological, and phonemic awareness, vocabulary development, and metalinguistic awareness. The studies with families participating in those program reported increased engagement through visual attention, babbling, and laughing. (Snoddon 2011, 2012). There are benefits of employing the patterns, rhymes, and language play in sign language, and they are incorporated in the SBA. For example, in the story, *Baobab*, the signer has a rhythm when signing "walk" as she sways her body while signing it. She signed, "A little girl loved to climb trees. Big, Medium, or Small. She loved them all." There's a pattern with handshape "5" when signing love climbing trees. She played with language by describing the tree as big, medium, or small with the same handshape, but showed different mouth movement and movement of hand to indicate size.

Fingerspelling as a Gateway: Chaining

Fingerspelling is a "bridge" between ASL and written English as it forms a natural connection between ASL (fingerspelling) and English (spelling) (Padden & Ramsey, 1998). Fingerspelling is seen as a part of phonological awareness (Chamberlain & Mayberry, 2008). Fingerspelling skill significantly predicted reading fluency, revealing for the first-time that fingerspelling is seen as a gateway to reading fluency in deaf bilinguals (Stone, et al., 2018). Recent studies have discovered the children's ability to understand fingerspelled words are strong predictors of reading skills (Padden, 1996; Padden & Ramsey, 1998). The studies suggest that early fingerspelling exposure helps deaf children become better readers, fingerspelling and literacy development are interrelated, and it facilitates vocabulary growth. "Chaining" is a procedure for connecting a sign to text, a printed word, written word, or a fingerspelled word. For example: A person could fingerspell H-O-N-O-R, then sign it, and then fingerspelling it a second time. Chaining words can have three to five parts. Example: Spelling the word, signing it, and spelling it again. Or the person can sign the word, spell it, point at the printed word, spell it again, and sign it again (Humphries & MacDougall, 1999). This VL2 storybook app includes chaining of fingerspelled and signed words for vocabulary words appearing in the app. Further vocabulary and spelling practice with sign and fingerspelling are offered at the end of the storybook glossary in the LEARN section. We also know that, in general, children using e-books use the online dictionary feature significantly more than a printed dictionary related to the same books (Grimshaw, et al., 2007). The glossary tool in this storybook app will be useful for promoting the vocabulary development in both languages.

Storybook Design

The platform is designed around the research-based features defined above. There are three interactive presentation modes: WATCH, READ, and LEARN. On the App's Home Page (Figure 1a), users can select the presentation mode with which they wish to engage. In WATCH mode (Figure 1b), children can see the story in its entirety in sign language. In READ mode (Figure 1c), they can swipe the page through the story as they would if they had a paper version of the book with text and original artwork; however, they may also tap on a "play" button and see the ASL translation of the single page of text on the screen (Figure 1c). Within the text itself, certain vocabulary words are highlighted; when children tap on a highlighted word, they are presented with a pop-up window showing the chained fingerspelled and signed version of the highlighted word (Figure 1d). Thus, on each page, children can choose English or ASL for a small segment (page) of the story and tap on individual words to see them signed and fingerspelled. In this LEARN mode (Figure 1e), there are list of same words that are highlighted in the READ mode of the story. When clicking on the word, the video pops up with the signer chaining the word (signing, fingerspelling, and signing the word again.) The glossary is based on single word and does not include phrases. It uses conceptually correct signs (matching the definition used in the story). It does not present multiple signs for the same English word, nor multiple English words for the same ASL sign.

Need for User Engagement Study

There are no known research studies exploring the app use behaviors of deaf children with varied backgrounds. This study is the first to explore these constructs with a view toward gaining insight into the optimal design approaches for future app development, the translation of research into age-appropriate educational resources, and the additional materials that may benefit children, parents, and educators. This study investigates how children spontaneously use the WATCH, READ, and LEARN modes as well as how they engage with the ASL, fingerspelling, and reading features built into the apps. We also investigate differences in app use for children with different levels of ASL skill and ASL narrative reading ability.

Research Questions and Hypotheses

There are several interrelated research questions in this study. What is the children's reading and viewing behaviors while using the VL2 storybook apps? Specifically, how do they allocate their time across the WATCH, READ, and LEARN modes? Do they employ the strategies for ASL/fingerspelling/reading mapping that are built into the apps? And of theoretical importance, do children with an early age of exposure (AOE) to ASL engage with the app differently from those with later exposure. Finally, are there relationships between reading skills, ASL skills, and ASL narrative skills? We hypothesize that children with an early ASL AOE will demonstrate greater engagement with the reading elements of the apps, will demonstrate better ASL skills, and will have higher levels of ASL narrative skills when asked to retell the story than will children with less exposure to ASL.

Method

Sample

Schools

Given that the SBAs are designed as bilingual tools for helping children establish links between their ASL knowledge and print English, we designed the current study to focus on children who were in bilingual ASL/English programs. We targeted children between the ages of 5 and 8 to correspond to the age appropriateness of the Baobab story for children in that age range. We recruited three ASL-English bilingual elementary school programs. We sent batches of consent forms to each of the three schools which were then distributed to children in the appropriate age range. Parents who consented were asked to complete a background questionnaire and return it to the school along with their consent form. Only the students with completed consent forms and questionnaires were identified for participation in the project.

At each site, a room was identified for conducting the study. Researchers took care that the identified rooms were similar in size to one another, that there was ample light, and that the rooms would have few distractions during the running of the study. At two of the participating schools, participants were tested after school. At the third school, students participated during the school day, and a coordinator from the school assisted by accompanying the participants to the room at a designated time.

All participants were tested individually, by a researcher who is deaf and a fluent native ASL user who received training in Elementary Bilingual Education in ASL and English. She was a high school level teacher for 8 years, and a research assistant in several language and cognitive neuroscience labs for 5.5 years prior to this study. The researcher was assisted by a deaf doctoral student, who provided general assistance and operated the video equipment.

Participants

Descriptive statistics of the 43 study participant characteristics are presented in Table 1. To summarize: a higher percentage of the sample was male; participants were evenly distributed across the age range from 5 to 8; just over half the participants (54%) were classified as having a profound hearing loss; just over two-thirds of the sample were reported as having been exposed to sign language from birth; over half of the participants were reported as having at least one deaf parent; about two-thirds of the participants were from Caucasian (white, not Hispanic) racial backgrounds; roughly two-thirds of the participants used assistive hearing technologies, most of whom had hearing aids (49%). Most children in the sample were reported as having tablet computers at home.

Given the importance of both the age of exposure to ASL and the age of the participants, we calculated the mean age (in months) at the time of the study for all participants. Since age of exposure to ASL was a major variable in our research design, we compared the ages of participants who had been exposed to ASL from birth to those who had been exposed after birth. Comparison statistics are presented in Table 2. Boxplots showing the distributions of age for these two groups are shown in Figure 2. Important differences can be noted. Participants with exposure to ASL from birth were significantly younger (as noted in the t-statistics presented in Table 4) and more highly varied in age. This significant difference reveals a potential confounding of age and age of exposure among the study participants and leads us to be cautious in interpreting any of the findings presented below examining the impact of age of exposure to ASL with any of the engagement measures..

Measures

Indicators of student engagement across the SBA presentation modes

Participants were videotaped throughout the study. Each child proceeded through the course of the study using a standardized protocol (see Figure 3), during which they first, received training and practice, followed by free engagement with each Mode (Watch, Read, Learn, and Free Play) for a specific length of time. The protocol is described more fully below. For each mode, a set

Figure 1. a) Storybook app: home screen; b) storybook app: watch mode. c: storybook app: read mode (ASL full sentence); d) storybook app: read mode (fingerspelling chained with ASL words); and e) storybook app: learn mode.

of quantitative indicators was developed for each presentation mode, as follows:

WATCH Mode (6 minutes)

- Number of seconds child remained on task
- Number of seconds attending to video during task
- Did the child end the task early? (Yes/No)
- Why might a child have ended early?
- Number of times child copied or practiced individual signs or phrases in ASL while engaging with app

READ Mode (3 minutes)

- Number of pages viewed during task*
- Number of times child pressed play to watch the page-level ASL translation*
- How many times the child pressed individual words to view signed and fingerspelled translations*
- Number of instances child copied/practiced signs or phrases in “Page-Play”*
- Number of signs copied or practiced from the vocabulary clips*
- Number of fingerspelled words copied or practiced from the vocabulary clips*
- Number of seconds spent on task
- If a child ended a task early, what was the maximum number of seconds spent on the task?

Table 1. Selected characteristics of the study sample

		Count	%
Gender	Female	18	40.9
	Male	26	59.1
Age	Five	9	20.9
	Six	10	23.3
	Seven	12	27.9
	Eight	12	27.9
Level of deafness	Mild	3	7.1
	Moderate	9	21.4
	Severe	7	16.7
	Profound	23	54.8
Exposed to sign from birth	No	13	30.2
	Yes	30	69.8
Are either or both parents deaf?	No	20	45.5
	Yes	24	54.5
Race	Unknown	2	4.7
	Caucasian	28	65.1
	African American	2	4.7
	Asian	4	9.3
	Latino	5	11.6
	Mixed/other	2	4.7
Assistive hearing devices	Cochlear implant hearing aid Both CI and	6	14
	HA BAHA (Bone conduction hearing aid) No	18	41.9
	assistive hearing device	2	4.7
		1	2.3
		16	37.2
Does child have tablet computer at home?	Yes	28	63.6
	No	5	11.4
	Data not available	11	25.0
How often does the child use the tablet computer at home?	Never	5	11.4
	Once or twice a week	8	18.2
	3 or 4 times a week	6	13.6
	Daily	14	31.8
	Data not available	11	25.0

Table 2. Means and standard deviations of age of participants for two age of acquisition groups: those exposed at birth and those exposed after birth

		Months of age at time of study		
		Mean	**SD**	**N**
Exposed to ASL from birth	No	92.23	7.73	13
	Yes	81.20	11.81	30
		$t_{(41)} = 3.083$, $p < .01$, *Cohen's* $d = 1.024$		

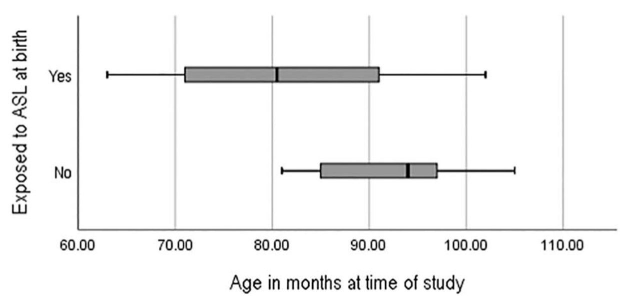

Figure 2. Boxplot of participants' age in months at time of study by whether participant was exposed to ASL at birth.

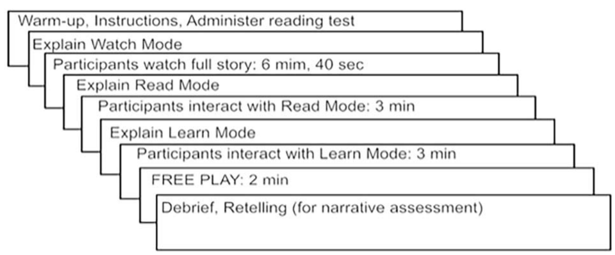

Figure 3. Design protocol for the storybook app engagement study.

- Why might a child have ended early?
- Number of words pressed multiple times
- Number of words pressed in sequential order (not necessarily every word in a row)
- Number of words pressed in non-sequential order (randomly)
- Number of times child copied or practiced both the signed and the fingerspelled words from the vocabulary clips
- Did the child seem meaningfully engaged during the task?

LEARN Mode (3 minutes)

- Number of times child pressed individual words to see signed and/or fingerspelled translations*
- Number of signs mimicked from vocabulary clips*
- Number of fingerspelled words mimicked from vocabulary clips*
- Did the child end the task early?
- If so, how much time was spent on task?
- Reason for finishing task early
- Number of times child watched the whole video
- Number of times child viewed the first sign only
- Number of times child viewed the first sign and the fingerspelling only
- Number of words pressed multiple times
- Number of times child copied both the signed and fingerspelled words from the vocabulary clips
- Were the words pressed at a moderate pace?
- Did the child press the words randomly (non-sequentially)?

Free Play (2 minutes)

- How much time, in total, did the participant spend in WATCH mode during free play?*
- How much time, in total, did the participant spend in READ mode during free play?*
- How much time, in total, did the participant spend in LEARN mode during free play?*
- How much time, overall, was the participant engaged in any mode during free play?*

**- Indicators that are included in the analysis below.*

Ratings of ASL skills

ASL Scale of Development (Herzig, 2002) was used as an instrument to rate the students' ASL skills. This scale, a five-point holistic scale (Beginner; Early Intermediate; Intermediate; Early Advanced; and Advanced), was designed and field-tested over 2-year time span. It was positively correlated with the Learning Records reading scales for both years, corroborating previous research findings linking fluency in ASL and reading achievement. (Allen & Herzig, 2005; Herzig, 2002; Humphries & Allen, 2008). This scale was based on considerations of a child's progression of interpersonal development, language proficiency, skills in storytelling/presentation, fingerspelling proficiency, and cultural behavior. Three independent raters were given training using the scale, after which they rated each participant, based on viewing the child's videotaped ASL narrative re-telling of the story and checking the transcript on the five-point scale corresponding to the five levels listed above.: The raters were evaluated regarding their levels of agreement using the weighted Kappa statistic (Cohen, 1968)[1]. The ratings of the two raters showing the highest level of agreement were averaged to determine the final rating used in the analysis. The Kappa statistics are presented in Table 3.

Ratings of ASL narrative skills

Stadler & Ward's (2005) Narrative Stages presents a developmental continuum of children's storytelling skills and is used to measure students' ability to retell narratives. This measure was based on *The Child's Concept of Story* (Applebee, 1978) and Stein and Glenn's (1979) model of narrative development based on story elements. Stadler & Ward (2005) revised the Applebee, Stein and Glenn's model and renamed the levels: labeling, listing, connecting, sequencing, and narrating (See Table 4.) It is worth noting that ASL narrative retelling styles of deaf and hard-of-hearing children have not been studied and may not reflect the typical style characterized by a single-topic focus and clear beginning, middle, and end (Collins, 1985; Jalongo, 2003). As with the ASL ratings, each of the three raters read the transcript and viewed the signers before rating the ASL narrative skill of each participant independently, and the two ratings of raters demonstrating the highest Kappa statistics were averaged to form the rating for the current study. Note: in Table 3 matrix, the Kappa indices for the ASL ratings appear below the diagonal of the raters' matrix, and those of the ASL Narrative ratings appear above the diagonal.

Table 3. Kappa values (weighted) among rater pairs for ratings of ASL narrative skill (above the diagonal) and ASL skill (below the diagonal) percentages of exact agreements are in parentheses

	Rater 1	Rater 2	Rater 3
Rater 1		0.373 (81%)	0.306 (76%)
Rater 2	0.677 (87.60%) ASL rating[a]		0.616 (87%) ASL narrative rating[b]
Rater 3	0.455 (86.05%)	0.579 (90.45%)	

[a]Raters 2 and 3 had the highest kappa for narrative skill (Kappa = .616) and the highest percentage of exact agreement. We calculated a composite score using those two raters. [b]For ASL skill we computed a composite based on the ratings of Raters 1 and 2 (Kappa = 0.677).

Table 4. Stadler and Ward's narrative developmental continuum

1- Labeling	Unrelated statements that label or describe
2- Listing	Statements about a central topic
3- Connecting	Statements about a central topic with perceptual rather than temporal links. Temporally related statements have no central topic.
4- Sequencing	Temporally related statements about a central topic; character goals and intentions as well as cause/effect or causality
5- Narrating	Temporally related statements about a central topic with a theme or moral. Developed plot.

Estimates of reading ability based on vocabulary word knowledge

Participant reading levels were measured using the San Diego Quick Assessment (SDQA; LaPray & Ross, 1969). The SDQA is a screening tool used to measures students' recognition of words presented out of context and selected to represent typical vocabulary at distinct levels of development. Weak readers often rely heavily on context, recognizing in-context words more easily than those out of context. This difference is much less pronounced in proficient readers. The SDQA was originally devised from words randomly selected from the glossaries of elementary-level books and from the 1931 *Teacher's Word Book of 20,000 Words*. A study conducted by Ekwall and Shanker (1988) found that this tool is useful for students whose first language is not English and is generally considered appropriate for culturally and linguistically diverse learners. While this study did not include deaf students and ASL users, Barie Blackley (2011) demonstrated that the SDQA adequately estimates a child's ability to read grade-level material.

In the current study, English words were presented one at a time from lists containing words that increased in difficulty. Participants were asked to read each word silently and to provide an ASL translation of the word. Accurate signs were deemed correct. Children who fingerspelled the words were prompted to supply a sign for the fingerspelled word for it to be scored as being correct. The student's reading level was defined as the last grade-level word list in which the student signed eight or more words correctly. The test continued until the student made three errors in a row.

Age of first exposure to ASL

On the background survey parents indicated the age at which their children were first exposed to ASL. Because of the small sample size, and a prevalence of students from signing families, the participants were divided into two groups: those who had been exposed to ASL from birth, and those whose first exposure to ASL occurred after birth.

Procedures

The procedures for the study tasks are summarized in Figure 3. Participants were videotaped throughout the study. To begin, the lead researcher asked participants a few warm-up questions to make the participants feel comfortable in the setting and to confirm their identity. The researcher then administered SDQR, a test requiring 4 minutes or less. Participants were then shown the full story in WATCH mode (roughly 6 minutes). When the story was finished. The researcher provided instruction on how to use the different features of READ mode. Participants were given adequate time to practice on using the different components of this mode. When the researcher was satisfied that the participants understood how to use all the different features of READ mode, the participants were given precisely 3 minutes to spend, on their own, interacting with the app in this mode. Next, the researcher provided instruction and practice time on how to use the features of LEARN mode, after which the participants interacted, on their own, in this mode for another three minutes. If the participants became restless during the READ or LEARN modes, they could ask the researcher to stop before the three minutes had elapsed. Lastly, the participants were given two minutes of "Free Play" during which they could return to any of the three modes or opt to end the study. The researcher demonstrated how the participants could switch among the three presentation modes.

Finally, after the Free Play period, the researchers asked follow-up questions to participants: *What do you think of the story? Thumbs up or thumbs down? What was your favorite part of the app: WATCH, READ or LEARN? Can you tell me what the story was about?* Responses to these questions formed the basis for the ASL skills and ASL Narrative assessments. At the end of the study, the researcher gave each participant a thank-you card with a $10 iTunes gift certificate, VL2 storybook app postcards, and stickers.

Transcription of Videos

All student videos were transcribed and translated into English glosses. All glosses and other forms of expressive language such as directional verbs, intensifiers, and non-manual markers were included. Coders were trained in the use of the engagement indicators, using a stopwatch, and through careful observation of participant behavior during the study.

Results

Participant Reading, ASL Narrative Skill, and ASL Levels

Means and standard deviations for the measures of Reading Level, ASL Narrative Skill, and ASL Skill are presented in Table 5. To examine the ranges of scores on these variables, we calculated means and standard deviations of scores from the bottom and top halves of the distributions. As the ranges of these variables were small, the median splits of these distributions into "Low" scorers and "High" scorers were created allowing us to examine variation in the levels of performance for lower and higher scorers, as well as the impacts of these levels on app engagement.

Correlations among ASL, ASL Narrative, and Reading measures are presented in Table 6. We note a high correlation between ASL Narrative Skills and ASL Skills, but nonsignificant correlations between Reading Skill and both ASL and ASL Narrative Skills. For Reading (primarily an English vocabulary measure) correlations with ASL skills and ASL Narrative skills are higher (though nonsignificant, due to small sample sizes) when we eliminate students whose reading score was equal to 0. This suggests that as students begin to master English vocabulary, there may be an emerging relationship between literacy and ASL development, a finding that is consistent with previously published research. Additionally, research also reveals an underlying proficiency link between ASL and English (Cummins, 1979). Cummins's theory of Common Underlying Proficiency (CUP) found that crossing the threshold in development of a first language aids in the acquisition of a second. The positive correlation between the reading scale placements and the ASL development scales found during field study of the ASL Scale of Development project indicates that ASL fluency might provide access to English and thereby serve as a springboard for advancing the literacy of deaf and hard of hearing children, a suggestion that echoes the findings of other researchers (Chamberlain and Mayberry 2000). The third level of scale, intermediate, of the ASL Scale seems to be a critical level of functioning for beginning readers (Humphries & Allen, 2008).

Table 5. Means and standard deviations of ASL skill rating (averaging the ratings of raters 1 and 2), narrative skill rating (averaging the ratings of raters 2 and 3), and instructional reading level (determined by scores on the SDQA). Overall means and subset means for low and high ability groups are presented

		Mean	SD	N
ASL skill rating	Total	1.49	0.98	43
	Low	0.75	0.57	24
	High	2.42	0.45	19
ASL narrative skill rating	Total	2.41	1.41	44
	Low	1.50	0.97	26
	High	3.72	0.73	18
Instructional reading level	Total	1.86	1.84	41
	Low	0.2	0.4	18
	High	3.3	1.3	23

Table 6. Correlations among three performance indicators: ratings of ASL skill, ratings of narrative skill, and instructional reading levels (Correlations based on sample eliminating participants whose reading level was 0 are presented in parentheses)

	ASL rating	ASL narrative rating
ASL narrative rating	0.82*	
Reading level	0.15(0.37)	0.23(0.40)

*$p < .01$

Table 7. Engagement Indicators in Read Mode (group 1) by whether child was exposed to ASL from birth

Was child exposed to ASL at birth?		Engagement indicator: read mode: number of pages viewed during the task	Engagement indicator: read mode: number of times the child pressed play to watch the page-level ASL translation	Engagement indicator: read mode: total number of times the child pressed individual words to view sign
No	*N*	12	12	12
	Mean	6.42	2.25	8.17
	SD	4.34	2.34	8.15
Yes	*N*	28	28	28
	Mean	8.96	2.61	6.43
	SD	7.04	3.18	6.40
		$t_{(38)} = -1.16$, $p = .25$	$t_{(38)} = -0.35$, $p = .73$	$t_{(38)} = 0.72$, $p = .47$
Total	*N*	40	40	40
	Mean	8.20	2.50	6.95
	SD	6.40	2.93	6.91

Table 8. Engagement indicators in read mode (group 2) by whether child was exposed to ASL from birth

Was the child exposed to ASL at birth?		Engagement indicator: read mode: number of discrete instances of child copying or practicing signs when viewing ASL pages	Engagement indicator: read mode: number of signs copied or practiced from the vocabulary clips	Engagement indicator: read mode: number of fingerspelled words copied or practiced from the vocabulary clips
No	*N*	12	12	12
	Mean	0.25	1.00	0.00
	SD	0.62	5.21	0.00
Yes	*N*	28	28	28
	Mean	0.61	2.00	0.14
	SD	1.91	5.21	0.45
		$t_{(38)} = -0.63$, $p = .53$	$t_{(38)} = -0.61$, $p = .54$	$t_{(38)} = -1.09$, $p = .28$
Total	*N*	40	40	40
	Mean	0.50	1.70	0.10
	SD	1.63	4.67	0.38

Engagement Indicators

Tables 7 and 8 present mean levels of engagement for selected indicators in READ mode. Means and standard deviations are presented for the total sample, and for groups of participants defined by whether they had been exposed to ASL at birth. To summarize: in the total sample, children viewed an average of just over 8 pages during the three-minute READ period, pressed the play button on average two and a half times to view the ASL translations of the page-level English passages, pressed highlighted vocabulary words on average about 7 times, copied or practiced signs from the ASL translations on average less than one time, copied or practiced signs on average just over one and a half times from the vocabulary clips, and almost never copied or practiced the fingerspelling of words from the vocabulary clips. None of the comparisons, using t-tests for independent samples, between participants who had been exposed to ASL from birth and those who had not, was significant.

Table 9 presents the mean levels of engagement for indicators in LEARN mode. On average, participants viewed just under 13 words in LEARN mode, practiced, or copied the ASL signs fewer than two times, and almost never practiced or copied the fingerspelling of the viewed words. None of the comparisons of participants with at-birth ASL exposure and after-birth exposure was significant.

During the free play period, participants spent, on average, 12 seconds in in WATCH mode, 32 seconds in READ mode, and 15 seconds in LEARN mode (Table 10). Though not statistically significant, children who had not been exposed to ASL from birth spent more time in WATCH mode (19.62 seconds) than those who had been exposed to ASL from birth (8.07 seconds). We note that the standard deviations for both groups are quite high, and, combined with the small sample sizes, the findings are interesting, but not conclusive, due to lack of statistical power. Regarding the amount of time spent in READ and LEARN modes, children with at-birth exposure spent significantly more time (using a .10 level of significance) than children with later exposure. It is noteworthy that no children with after-birth exposure spent any time in LEARN mode.

We were curious to discover the total amount of engagement, independent of mode, for the sample as a whole and for the groups defined by whether the child had been exposed to ASL from birth. The results are presented in Table 11 and shown in Figure 4. Considering the whole sample, the mean number of seconds engaged in the app during the 2-minute free play was 57.47 seconds. There was a significant difference between those participants who had been exposed to ASL from birth (Mean = 71.83 seconds) and those who had been exposed after birth (Mean = 28.77). The difference was more than .8 of a standard deviation.

Finally, we evaluated the relationships among the ASL skills, ASL Narrative, and Reading Levels and the times spent engaged in the three presentation modes during free play. These are presented in Table 12. As noted above, we split the participants into

Table 9. Engagement indicators in learn mode by whether child was exposed to ASL from birth

Was the child exposed to ASL at birth?		Engagement indicator: learn mode: total number of times the child pressed individual words to view vocabulary clips	Engagement indicator: learn mode: number of signs copied or practiced from the vocabulary clips	Engagement indicator: learn mode: number of fingerspelled words copied or practiced from the vocabulary clips
No	*N*	11	11	11
	Mean	13.00	2.00	0.36
	SD	10.23	5.04	0.67
Yes	*N*	28	28	28
	Mean	12.71	1.50	0.28
	SD	13.98	5.07	1.15
		$t_{(37)} = 0.06$, $p = .95$	$t_{(37)} = 0.28$, $p = .78$	$t_{(37)} = 0.21$, $p = .83$
Total	*N*	39	39	39
	Mean	12.80	1.64	0.31
	SD	12.90	4.99	1.03

Table 10. Engagement indicators during free play by whether child was exposed to ASL from birth

Was the child exposed to ASL at birth?		Engagement indicator: number of seconds spent in watch mode during free play	Engagement indicator: number of seconds spent in read mode during free play	Engagement indicator: number of seconds spent in learn mode during free play
No	*N*	13	13	13
	Mean	19.62	9.15	.00
	SD	44.65	33.01	.00
Yes	*N*	30	30	30
	Mean	8.07	41.97	21.8
	SD	26.40	56.45	43.57
		$t_{(41)} = 1.06$, $p = .29$	$t_{(41)} = -1.95$, $p = .06$	$t_{(41)} = -1.79$, $p = .08$
Total	*N*	43	43	43
	Mean	11.56	32.05	15.21
	SD	32.86	52.38	37.60

Table 11. Mean number of seconds spent in any engagement during free play

Was the child exposed to ASL at birth?		Number of seconds spent in any engagement during free play
No	N	13
	Mean	28.77
	SD	51.90
	SEM	14.39
Yes	N	30
	Mean	71.83
	SD	57.34
	SEM	10.47
	$t_{(41)} = -2.324$, $p = .025$, $d = 0.83$	
Total	N	43
	Mean	57.47
	SD	58.64

"High" and "Low" ability groups on each measure to allow for group comparisons on the engagement indicators. For all three skill areas, High and Low ability groups did not differ in the amount of time participants spent in each of the three presentation modes during the Free Play period. There was some evidence that the children in the High ASL skill group spent more time in Read Mode during free play than did children in the low ASL ability group (average time in Read mode as 59.32 versus 40.22, t-statistic probability = .101). As with the comparisons presented above, we also compared the total amount of engagement in free time (summing across the three modes) for the High and Low Ability groups among the three measures. These results are resented in Table 13. No significant differences are reported for High-Low comparisons for any of the Independent Variables.

Discussion

The current study sought to evaluate deaf children's self-motivated engagement with the ASL-English bilingual Storybook iPad App, *The Baobab*, developed at the National Science

Table 12. Number of seconds spent in watch, read, and learn modes during free play by groups defined by high and low ASL skill, narrative skill, and instructional reading level

		Watch mode			Read mode			Learn mode		
		Mean	SD	N	Mean	SD	N	Mean	SD	N
ASL skills	Low	10.08	29.28	24	17.38	40.22	24	22.04	43.36	24
	High	13.42	37.64	19	44.26	59.32	19	6.58	27.48	19
		$t_{(41)} = -0.327$, $p = .745$			$t_{(30.34)}$ [a] $= -1.692$, $p = .101$			$t_{(37.32)} = 1.423$, $p = .163$		
ASL narrative skills	Low	5.27	16.92	26	24.77	47.78	26	20.38	42.00	26
	High	20.00	46.02	18	40.78	57.63	18	6.89	28.24	18
		$t_{(20.21)} = -1.299$ $p = .209$			$t_{(32.09)} = -0.970$, $p = .339$			$t_{(41.983)} = 1.274$, $p = .210$		
Instructional reading level	Low	8.84	27.60	19	33.84	53.24	19	16.42	38.63	19
	High	14.30	37.64	23	26.74	50.35	23	14.87	38.29	23
		$t_{(40)} = -0.526$, $p = .602$			$t_{(40)} = 0.443$, $p = .660$			$t_{(40)} = 0.130$, $p = .897$		

[a]Fractional adjusted degrees of freedom for the t statistics presented in this table are presented for those comparisons for which equal variances could not be assumed.

Table 13. Mean and SD of total seconds of engagement in any mode during free play for participants above (high) and below (low) median levels on each independent variable

		Seconds spent in any mode during free play		
		Mean	SD	N
ASL skill level	Low	49.50	57.35	24
	High	64.26	60.52	19
		($t_{(41)} = -0.818$, $p = .418$)		
ASL narrative skill level	Low	50.42	57.48	26
	High	67.67	60.45	18
		($t_{(42)} = -0.958$, $p = .344$)		
Instructional reading level	Low	59.11	60.38	19
	High	55.91	58.36	23

($t_{(40)} = -0.174$, $p = .863$)

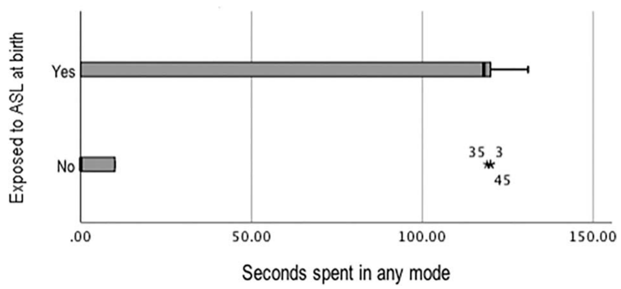

Figure 4. Boxplots of seconds spent in ANY mode during free play by whether participants were exposed to ASL at birth.

Foundation/Xxxx University Science of Learning Center on Visual Language and Visual Learning. We developed a set of engagement indicators (e.g., number of clicks on specific interactive stimuli in the App, number of pages looked at, etc.), based upon an analysis of previous research that examined childhood behaviors and curriculum design principles for early literacy learning. We were especially focused on principles of learning that might influence the design of learning apps (Hirsh-Pasek, Adamson, et al., 2015, Hirsh-Pasek, Zosh, et al., 2015). Additionally, we sought to examine the relationship between the developed engagement indicators and several independent measures including whether the child had been exposed to ASL from birth and the child's levels of ASL skill, ASL narrative skill, and grade-level mastery of English language vocabulary words.

Results demonstrated a good level of overall engagement: in a 2-minute period of free play, children (aged 4–5), were actively engaged (without teacher guidance) on average for more than 57 s. While in read mode, they looked, on average, at more than eight pages, and clicked on close to seven individual vocabulary words. Engagement with the reading mode was correlated with both the exposure to ASL from birth and a measure of ASL skill. This was unsurprising, as both the reading and ASL pages in the app would be extremely vexing for children with neither ASL skill nor reading skill. Further work on a bilingual app for children with little or no ASL or English skill is needed to engage these students.

Participants with any background experience are highly engaged with the SBA. They understand and use the interactive features of the app. They tap words in "Read" mode more often than they view the ASL videos on each page. Most importantly, early ASL exposure seems to affect students' free play choices. Additionally, it is possible the design features influence their interest. There are no animation or illustrations to entertain them in the LEARN mode. The LEARN mode only consists of words and videos of a person signing and fingerspelling. This may be beneficial for parents or new signers who want to focus on learning signs on a word level before moving on to the whole story part.

Throughout the study, there were very few instances of students mirroring or copying the fingerspelling or signs they saw on the screen. Such active copying would be critical to ensure learning through more active involvement with the material.

Because participants did not practice fingerspelling or mimic the signs, there is a need for strategies to promote deeper interactions. As Oakley et al. (2020) suggest, pairing the SBAs with open-ended creative apps, such as tasks suggesting re-enactments of different portions of the story and requiring social interaction with teachers and other children, might facilitate greater incentives for reading the texts and/or in fingerspelling the words being learned. Social interaction is essential for early language learning (Kuhl, 2007). Adding a game component to an app may encourage active exploration towards a learning goal. The learner should have "opportunities for self-directed activities through play and other exploratory adventures as a means of self-stimulation and healthy development" (Sigel, 1987, p. 214). The games can stimulate students' phonological aspects of sign language by matching handshapes to pictured objects and building up the metalinguistic skills to vocabulary comprehension, bridging fingerspelled words to printed words by having the student pick out the correct word the person fingerspelled, as suggested by McQuarrie and Abbott (2013). For reading comprehension, games can involve filling in the blanks or putting events in correct order.

One notable finding is that students with exposure to ASL after birth spent less time in the "Read" and "Learn" modes. There is a clear need for developing direct instruction materials (Klahr & Nigam, 2004). The overall ASL and literacy skills play a role in how students use the apps. They may need more support with bridging sign language to English print. Combining direct instruction with exploratory learning may be an effective strategy (DeCaro & Rittle-Johnson, 2012). When students search for the answers themselves before receiving direct instruction, they show better conceptual understanding.

Educators can use this app to promote metalinguistic awareness, especially in an ASL Language Arts curriculum. This ASL story includes many complex linguistic structures such as role shifting and locative classifiers. Once young, emerging readers comprehend ASL grammatical structures, the resulting metalinguistic awareness can help them learn English (Cummins, 1996, Krashen, 1992). Providing access to these SBAs or sole direct language and literacy instruction may not be as effective as when students experience both (Kagan & Lowenstein, 2004).

Because ASL narrative retelling aids literacy development, giving students opportunities to retell stories may be beneficial. These activities can promote ASL literacy in deaf children because they necessitate more complex language than social conversation (Bailes, 2001). The grammar and patterns deaf children use when retelling ASL stories enables them to spend sharing or invent new stories. Future research should explore the content of the XXX storybook apps, how children engage with them, and how these apps affect their learning of vocabulary words and subjects. As well, the incorporation of more game elements into the apps, perhaps utilizing more up-to date technologies such as artificial intelligence, augmented reality, and sign recognition will increase student engagement, and enhance learning.

Limitations

The purpose of the current study was primarily to determine whether the ASL-English Bilingual iPad storybook apps are a viable platform for engaging deaf students in ASL and English literacy activities using interactive touch-screen technologies. While the study provides evidence that supports the use of this platform, there are some limitations that should be noted. First, the sample was small and was limited to young children between the ages of five and nine attending schools for the deaf. Generalizations to other schools for the deaf, other school types, and to children of different ages are not possible.

As noted earlier, the age of the participants was correlated with whether the participants had been exposed to ASL from birth (younger participants were more likely to have an at-birth age of exposure to ASL). Thus, the major findings of the study, that is, that children exposed to ASL from birth and those with greater ASL skills have greater levels of engagement in Read Mode than those with lower ASL skill levels, must be interpreted cautiously. It is possible that older children have lower levels of interest in the subject matter of the apps, and therefore show lower levels of engagement across all the study modes.

The tasks in this study were designed to assess self-motivated engagement, without teacher of parent intervention. Since the apps are most likely employed within an educational environment, this self-motivated engagement may not fully represent typical involvement of children with the tasks.

Finally, we emphasize that the current study was designed to assess usability and engagement. The results do not directly imply that they are effective learning tools. Other studies, designed to assess learning efficacy will be required.

Conclusion

The VL2 storybook apps are a novel and potentially beneficial addition to existing bilingual stories for deaf children. To ensure that they are effective for children's language and literacy development, developers need to be aware of issues related to the use of iPad apps, about the science of learning, and theories in educating children learning English (in print) as a second language. Nearly a decade has gone by since the first storybook app was introduced. Since that time, there have been many technological improvements, such as the use of artificial intelligence that might help guide the sequencing of material to fit the unique learning needs of individual children, and the use of augmented reality that could bring children into the 3D worlds of the stories presented. Also, various gaming strategies might enable the incorporation of in-time learning assessments of student learning into the apps that could provide teachers and parents with critical formative information that could improve learning.

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Conflicts of Interest

No conflicts of interest were reported.

Endnotes

[1]The Kappa statistic (for binary outcomes; Cohen, 1960) and the weighted Kappa statistic (for ordered outcomes with three or more categories; Cohen, 1968) are commonly used measures of inter-rater agreement that range from 0 to 1, with 1 indicating perfect agreement. They have an advantage over a simple percent agreement, in that they adjust for chance-level agreement. The weighted Kappa has a further advantage for judgments that are made for ordered categories, such as those in the ASL and ASL Narrative skills judgments employed in the current study. In the weighted Kappa, raters who disagree by only one adjacent category (1 versus 2, for example) are credited as being more in agreement than raters who disagree by 2 or more categories (1 versus 3, for example). The farther apart any two ratings are for ordered categories, the less the agreement.

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