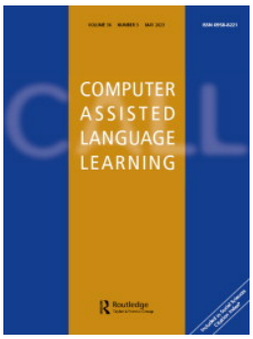

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The impact of mobile application features on children's language and literacy learning: a systematic review

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ABSTRACT

Mobile touchscreen applications present new opportunities for children's language learning. This systematic review synthesizes the evidence on the impact of features of mobile applications on children's language learning. Experimental studies published from 2010 onwards with children aged 3 to 11 years old were included. Of the 1,081 studies screened, 11 studies were identified, which examined four features of mobile touchscreen applications: inbuilt narration, real-time conversation prompts, augmented reality (AR), and hotspots. Inbuilt narration had a positive impact on story comprehension and word learning compared to reading alone but not shared reading with an adult. Real-time conversation prompts improved the quality and quantity of adult-child talk, and AR supported language learning ostensibly via increased motivation. No evidence was found for an impact of text-relevant hotspots. Limitations of the existing literature are discussed, and a strong case is made for further research in the area, particularly that which builds on learning theory and existing qualitative research.

KEYWORDS

Children;
language education;
mobile applications;
mobile assisted language learning;
systematic review

New technologies can provide new opportunities for gaining language and literacy skills for adults and children. The field of Mobile Assisted Language Learning (MALL) has generated promising insights on language learning using digital technologies for adult learners (Lin & Lin, 2019; Sung, Chang, & Yang, 2015), and emerging research on mobile, touchscreen devices such as tablets and smartphones with adults and children suggests that these now ubiquitous tools can support language skills too (Godwin-Jones, 2017; Neumann & Neumann, 2017). Looking beyond questions of *whether* such technologies can support learning, new empirical research is exploring *how*, by examining which specific features of mobile touchscreen devices have an impact on language learning (Jin,

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2018; Tai, Chen, & Todd, 2020). For children, who are at a critical stage in their development, research on this topic is also growing. In this systematic review, experimental and quasi-experimental research with children which demonstrates a causal impact of features of mobile touchscreen devices on language learning will be synthesized to make recommendations for educators and application designers and create a foundation for evidence-based language application design.

Children are increasingly using mobile touchscreen devices (Ofcom, 2019), for both leisure and learning, at a critical stage in their language development. Smartphone and tablet ownership are rising, with up to three quarters of 4-year-olds in the USA owning their own mobile device (Kabali et al., 2015) and children in the UK increasingly use these devices instead of laptop or desktop computers (Ofcom, 2019). By 3 years, children are able to tap and swipe independently on such devices (Marsh et al., 2015; Vatavu, Cramariuc, & Schipor, 2015), opening up possibilities for independent learning. The ubiquity of these devices enables learning to be extended outside of formal learning environments (Erstad, 2012).

At the same time, between the ages of 3 and 11 years old, children's language and literacy skills develop significantly, with gains in vocabulary, grammar, and pronunciation, and the emergence of reading and writing (D'Angiulli, Siegel, & Maggi, 2004; Honig, 2007). Furthermore, most children worldwide are learning a second language at this age, either as the medium of instruction (UNESCO, 2016) or a foreign language (Eurostat, 2015; Qi, 2016). However, a large proportion of children fail to reach age-appropriate targets for reading and writing skills by age 10 to 11 years (Department for Education, 2019; National Center for Education Statistics, 2019). Thus, leveraging mobile touchscreen devices could have a significant impact in supporting the development of language and literacy skills in both first and additional languages.

Access to and use of certain digital technologies, including mobile applications (apps), is positively associated with language skills. For example, playing digital games (Sundqvist, 2019) and using websites (Arndt & Woore, 2018) in a second language is related to superior second language skill. Similarly, children's skills in their first language have been correlated with access to literacy apps (Neumann, 2016). However, the nature of the relationship within such correlational studies is uncertain: for instance, those with stronger language skills may choose to play games in a second language, or other factors such as socioeconomic status could account for the relationship. Nonetheless, intervention studies have shown a causal benefit of educational literacy apps to children's literacy skills (Cho, Lee, Joo, & Becker, 2018; Rachels & Rockinson-Szapkiw, 2018; Tsai & Tsai, 2018). For example, Neumann (2018) found that preschool children who used three commercially

available literacy apps for 30 minutes a week for 9 weeks improved in letter name and phoneme knowledge, print concepts and writing, compared to a business-as-usual control group. This and similar findings imply that apps have potential to be useful educational tools for supporting language skills, which can partly allay concerns from parents and educators that access to digital media has a negative impact on children's development (e.g. George & Odgers, 2015). However, these kinds of intervention studies do not isolate which features of the interventions are effective. This is due to both the componential nature of the interventions - that is using multiple apps with multiple design features - and the use of non-digital media as a control condition, which vary from digital media in several dimensions. Thus, these educational intervention studies answer the question of whether mobile applications have potential to support learning, but not why they are effective. Therefore, they provide limited evidence to build theory on what makes effective practice within children's mobile language-learning.

Research is beginning to address more nuanced questions about the effective design of mobile applications for children's learning. Like any other pedagogical tool, mobile applications can vary widely in the effectiveness of their design, with many educational apps on the market failing to provide developmentally appropriate supports (Callaghan & Reich, 2018). As a first step in evaluating the educational quality of apps, rubrics have been developed by researchers which apply principles from learning theory (such as scaffolding and motivational theories) and draw on empirical research with older technologies, such as television and desktop computers (e.g. Hirsh-Pasek et al., 2015; Papadakis, Kalogiannakis, & Zaranis, 2017). These rubrics provide dimensions upon which the quality of educational apps can be evaluated by researchers, teachers, or parents. Thus, researchers are applying general theories of learning to support more effective app selection and design.

A starting point for research on the effective design of mobile applications for children's language learning is to examine the affordances they offer, and to consider how they may impact learning based on existing theory in language learning. An illustration of features of mobile touchscreen devices is shown in Table 1. Some affordances of apps on mobile, touchscreen devices are essentially analogues of non-digital learning tools: for instance, reading plain text on a screen is similar to reading plain text on a page. However, mobile applications also have features that are relatively unique, for example, the portability of the devices; possibilities for social interaction; multimedia input; and sensitivity to the physical context (Pachler, Bachmair, & Cook, 2010), as well as more advanced language processing tools including speech recognition and translation. For the target age group of younger children,

Table 1. Features of mobile touchscreen devices relevant to language learning.

Category	Examples of features
Multimedia output	auditory (sound effects, text-to speech, music, sound playback); visual (picture, animation, video); haptic (vibration); 3D (virtual reality)
Multimedia input	auditory (microphone); visual (camera); haptic (touching gestures, drawing, tilt/movement)
Social interactivity	competitive interactions; collaborative interactions; parasocial interactions; interaction prompts (e.g. real-time conversation prompts)
Language processing	speech recognition; translation; multiple keyboards; spell check; predictive text; dictionary
Motivational	rewards; gamification
Autonomy	independent use and accessibility; self-pacing; repetition
Personalisation	feedback; adaptivity; analytics; settings; customisation
Automated assessment	analytics for teachers/parents
Functionality	saving/recording inputs; ease of editing
Portability & ubiquity	use in multiple contexts
Context sensitivity	augmented reality; QR codes; location
Connectivity	sharing; web

mobile touchscreen devices are easier to hold and use independently than other devices such as laptops (Marsh et al., 2015; Vatavu et al., 2015), presenting opportunities for different forms of autonomous learning. These devices are also highly portable allowing children to use them in varied learning and recreational contexts (e.g. bedtime stories, play with toys, den-making) and translate them between these contexts (Marsh et al., 2018), and can be oriented flexibly to support collaborative learning (Falloon & Khoo, 2014).

Thus, affordances of mobile applications have the potential to support learning in new ways, in line with existing research on children's language learning processes, and this potential needs to be explored empirically. There are numerous ways in which the many affordances listed in Table 1 could support language learning, but for illustrative purposes we will give two examples. One such example is the potential for speech recognition to support writing. When writing, children have to orchestrate both transcription (typing or handwriting words and spelling) and composition (selecting words and crafting sentences) simultaneously. This places high demands on working memory (Kim & Schatschneider, 2017), especially for young children who are developing both of these skillsets. Speech recognition -which is a feature included in mobile touchscreen devices - has the potential to reduce this working memory load, by removing the need to transcribe, and thus to support young children in composing extended texts (Baker, 2017). A further example could be the potential for augmented reality as a support for learning print. Pre-literate children begin to learn print from identifying it in their environment (Horowitz-Kraus, Schmitz, Hutton, & Schumacher, 2017). Mobile touchscreen devices have camera input and capacity for

augmented reality (AR) features (e.g. superimposing animations over camera images). Thus, they could support children to identify and record use of text in their environments, as well as augment this with multimedia features (e.g. sound representations, letter highlighting, or motivational animations). This should have implications for learning, as it would allow children to independently explore letter-sound and orthography-phonology correspondences critical for learning to read (e.g. Frith, 1986). Therefore, there are many hypotheses for how features of mobile applications could impact children's language learning, which need to be tested in empirical research.

Qualitative studies indicate possible links between features of mobile learning devices and language learning outcomes (Baker, 2017; Falloon, 2013; Fantozzi, Johnson, & Scherfen, 2018; Hutchison & Beschorner, 2015; Levinson & Barron, 2018; Mogyorodi, Brathwaite, McGlynn-Stewart, Maguire, & Hobman, 2019; Terantino, 2016; Wang, Christ, & Mifsud, 2020). For instance, Fantozzi et al. (2018) identified a number of supportive affordances of storytelling apps used by preschool children, such as the capacity for multiple voice input and sharing creations with parents. Observations after using the storytelling apps suggested that children were more confident in speaking, and in interviews parents reported having more conversations about their school activities at home. The authors also noted some possible limitations of the apps used, such as that with autonomous use some children may not be challenged enough. In another study, interviews and observations with immigrant families of 5 to 7-year-old children revealed app features which might support second language learning, for instance using the speech-to-text function combined with a translation service to discover the meaning of heard words (Levinson & Barron, 2018). However, in order to verify a causal impact of features on learning, experimental studies need to be conducted.

The present review

Therefore, given the current ubiquity of mobile application use in children, the diversity of applications and their features that are available, and the ambiguity of much existing research regarding which applications are effective for learning and why, experimental studies are critical to assess the effectiveness of features educational apps for language learning. At this juncture in the research, a review of the existing literature is essential. Whilst quantitative studies have been conducted to begin to address the question of the impact of specific app features on children's language learning, the literature is currently very dispersed. Research takes place across many disciplines (psychology, education, computer science), and likely relates to many different features of digital devices (see Table 1).

One previous review has been conducted examining the effect of specific features of digital books on children's language learning (Takacs, Swart, & Bus, 2015). This meta-analysis examined the impact of multimedia and hotspot features of e-books (including computer, CD-ROM, and app books) on children's comprehension of stories and vocabulary learning. They found that multimedia features had a significant positive effect on story comprehension and expressive vocabulary, but that interactive features including hotspots, games and dictionaries had negative impacts. Takacs et al. (2015) explain these findings with reference to the cognitive theory of multimedia learning (Mayer, 2014): specifically, they suggest that multimedia enable simultaneous processing of verbal and non-verbal information which facilitates learning, whereas hotspots with extraneous information lead to cognitive overload. This review provided a significant contribution to our understanding of how these two features of e-books impact children's learning across e-book formats, compared to non-digital media.

The present review builds on this, with a focus on mobile touchscreen devices specifically, due to their increasing prominence in children's lives and distinct features highlighted above. By focusing only on these devices, it allows a more detailed analysis to be made of the findings related to different features. As such, the review is also not narrowed to any specific features, but instead is inclusive of any features of apps which have been investigated in terms of their impact on language and literacy learning. Furthermore, the remit of the present review is limited to studies with more directly comparable control groups (i.e. two app conditions with or without a feature, rather than an app compared to a physical analogue) to ensure that any differences are driven by the feature rather than the format.

The aims of the present review are as follows:

1. To synthesize and critically assess the existing experimental and quasi-experimental research examining the effect of features of applications on mobile touchscreen devices on language learning in children.
2. To use this synthesis and critical assessment to provide insights for educational instruction and design and pointers for further empirical investigation.

To address these two aims, a systematic review was conducted. The objective of the review was to identify all experimental and quasi-experimental studies examining the effect of any feature of mobile touchscreen devices on children's language or literacy skills: specifically, these studies needed to manipulate one feature of an app and compare

performance to a control group using the same app with that feature removed. This is because only these studies can demonstrate a clear causal link between a feature of apps and learning outcomes. The review strategy was open to any features of applications relevant to language learning. The population was limited to primary school aged children (3 to 11 years): this age range was selected because during this period, children have already established (Honig, 2007) and continue to develop their oral language skills (e.g. vocabulary, Beitchman et al., 2008; Verhoeven, van Leeuwe, & Vermeer, 2011), and build the foundations for literacy (Molfese et al., 2006; Pullen & Justice, 2003; Silvén, Niemi, & Voeten, 2002), whereas the language skills of children in earlier or later stages are likely to be very different and require different supports. The population was also restricted to typically developing children, because children with disabilities or developmental disorders that affect language learning have their own distinct learning needs. Separate reviews of technologies for atypically developing populations would be a valuable future contribution to the field.

Method

Search strategy

Three databases were searched: Scopus, Web of Science, and ProQuest's Education Collection. The first two databases are two of the largest citation databases for science, and the latter is an index of over 1,000 journals in education, so in combination allow a highly comprehensive search of the relevant fields. Final search terms used are shown in Table 2. The initial terms were selected to cover the range of language and literacy skills (reading, writing, speaking, listening; Burns & Siegel, 2018) and levels of linguistic knowledge (phonetics, phonology, morphology, semantics, syntactics and pragmatics; e.g. Akmajian, Demers, Farmer, & Harnish, 2010). Search terms were refined using an iterative process based on reviewing abstracts of returned articles and adding or removing search terms. Some terms which generated a lot of irrelevant articles, due to being quite general (e.g. language) were adjusted or substituted. The goal was to have comprehensive coverage of language and literacy skills and inclusive terms for the age group and technology. The NOT terms were included to reduce the number of articles returned with the wrong age group (e.g. *undergraduate* students); or domain of learning (e.g. *health* literacy); or medical articles which connected with the alternative meaning of 'tablet' as in medication (e.g. disease).

The protocol for the review is shown in Figure 1. The first search was conducted on 27th March 2019, with search alerts subscribed to until

Table 2. Search terms used in the systematic review.

Population	AND	Technology	AND	Language and literacy skills		NOT	Irrelevant terms
Child*		App		"Letter knowledge"	Literac*	Undergraduate*	
Tween*		Apps		"Letter nam*"	Write	"college student*"	
Preschool*		"Mobile app*"		"Letter sound*"	Writing	Graduate*	
Nursery		"Mobile game*"		"Letter form*"	Handwrit*	"higher education"	
Kindergarten*		"Mobile learn*"		"Verbal abilit*"	Spell*	"further education"	
"Primary school"		Tablet		"Verbal intelligenc*"	Read*	University*	
"Elementary school"		Tablets		"Print concept*"	Decod*	"health literacy"	
"Early learn*"		iPad*		"Print knowledge"	Orthograph*	"safety literacy"	
Student*		Touchscreen*		"Story-telling"	Phonolog*	Drug*	
		E-book*		"Story-making"	Phonem*	Medic*	
		"Digital story*"		"Word learn*"	Morpholog*	Disease*	
		"Digital book*"		"Word knowledge"	Vocab*	Nutrit*	
		"Electronic book*"		"Oral language"	Gramma*		
		"Electronic storybook*"		"Written language"	Pragmat*		
		"Digital game*"		"Language skill*"	Synta*		
		"Augmented reality"		"Language learn*"	Pronunc*		
				"Receptive language"			
				"Expressive language"			
				"Reading comprehension"			
				"Language comprehension"			
				"Story comprehension"			
				"Listening comprehension"			
				"Communicative competence*"			
				"Communicative skill*"			
				"Foreign language*"			

Note: University was removed from the NOT terms for Scopus as including this excluded a large proportion of articles.

27th March 2020. One search was conducted for each database using all the search terms, linked by the AND, OR and NOT operands. Search terms were applied to abstracts, titles and keywords, and filtered for journal articles published from 2010 to 2019. Only research articles from 2010 onwards were searched because this was the year that the first major tablet (the iPad) was released. Other mobile touchscreen devices (i.e. smartphones) were rarely used at home by under-12s prior to 2010 (Ofcom, 2009). Searches were exported to a Mendeley library. The full list of retrieved articles is available in .csv format at https://osf.io/43m69/.

Inclusion and exclusion criteria

All articles were screened by the first author to determine if they met the exclusion criteria. Titles and abstracts were screened to ensure

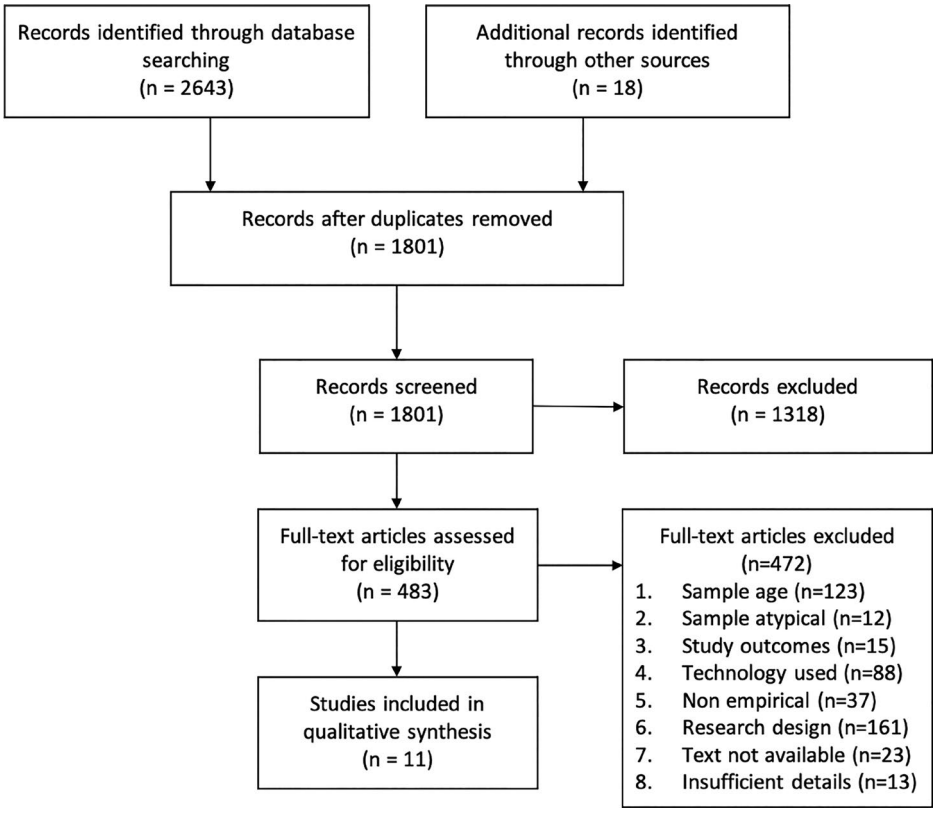

Figure 1. Systematic review protocol.

articles fit within the scope of the review. Articles were removed at this stage if one or more of the following exclusion criteria applied:

1. Sample age group was younger than 3 or older than 11 years old.
2. Sample had developmental disorders or disabilities which affect language (including dyslexia, autism, speech or language disorders, learning disability, visual impairment, or hearing impairment).
3. Study outcomes were related to topics other than language and literacy (e.g. maths, science, music, art, or digital literacy).
4. Technology other than apps on mobile, touchscreen devices was used (e.g. CD-ROMs, laptops).
5. Article is a review, a descriptive or theoretical paper (i.e. does not report any new empirical data).
6. The research design clearly did not allow it to address the question for the review (for example using apps or tablets only as a data collection tool; measuring general patterns of tablet or media usage, or attitudes to technology; or describing general implementation of tablet use in educational settings).

7. Full text article not available or not in English.

If excluded, texts were tagged for the most prominent reason for exclusion. If abstracts were ambiguous on any of the exclusion criteria, full texts were scanned to verify. Full texts of remaining articles were then scanned to ensure that they met the following inclusion criteria:

1. Article contained sufficient details of the relevant feature of apps used.
2. Article reports at least one outcome measure related to language and literacy learning behaviour or cognition (i.e. not only perceptions or attitudes). For example, this included, but was not limited to, narrative comprehension, receptive and expressive vocabulary, grammar, print knowledge, decoding, pronunciation, spelling, and writing.
3. The research design experimentally isolates the effect of an app feature on a language or literacy learning outcome.

Criterion 3 excluded studies that: had a qualitative design; manipulated multiple features of apps simultaneously; had no control group; or had a control group with confounds (e.g. including only a non-app control). Quasi-experimental studies which had a control group but randomised by group (e.g. class) rather than individual were included.

Additional search strategies

Three other strategies were used to find additional papers. Firstly, new article alerts for Web of Science, Scopus, and ProQuest Education Collection were subscribed to between March 2019 and March 2020. After screening abstracts this resulted in 8 further articles. Secondly, back-searching of references was performed on the five most recent and relevant review articles found during the search (Cho et al., 2018; Klímová, 2018; Neumann & Neumann, 2017; Takacs et al., 2015; Tsai & Tsai, 2018), resulting in 5 further articles after screening abstracts. Thirdly, to identify in press or online first articles, the 10 journals most frequently publishing quantitative studies relevant to our search were hand-searched for relevant articles in May 2019. The journals searched were: Computer Assisted Language Learning, Computers & Education, Early Childhood Education Journal, Early Childhood Research Quarterly, Educational Technology & Society, Frontiers in Psychology, Journal of Computer Assisted Learning, Journal of Educational Computing Research, Journal of Experimental Child Psychology, Reading & Writing. This resulted in 2 additional articles after screening abstracts.

Review approach

A narrative review approach was taken to synthesize the identified articles (Ferrari, 2015). A quantitative approach (meta-analysis) was not suitable for two reasons. Firstly, due to the diversity of potential features of mobile touchscreen devices and language skills included in the review, combining the results of such diverse studies would not produce meaningful results. Secondly, the relatively small number of studies that met inclusion criteria entails than any quantitative approach would be underpowered.

Results

Characteristics of included papers

A summary of all 11 studies included in the review is shown in Table 3. Of the 11 papers, 7 papers were published from 2018-2020, suggesting that this is an emerging field of research. The papers were also published in journals across a range of disciplines, including language studies (Reading and Writing), psychology (e.g. Early Childhood Research Quarterly), and computer science (e.g. Computers in Human Behavior). All of the papers implemented apps in a formal study context, with none being used in the digital wild. The majority of the papers (7 out of 11) were focused on children's skills in their first rather than a second language, and for the majority (8 out of 11) the activity was an e-book. The most common aspects of language learning measured were story comprehension and vocabulary or word leaning, with studies also looking at parent-child talk, pronunciation, and engagement with learning. Four features of devices were investigated: these were inbuilt narration (5 studies), real-time conversation prompts (2 studies), interactive hotspots (2 studies), and augmented reality (2 studies). The results will be discussed separately for these four features.

App features and impact on language learning

Inbuilt narration

Inbuilt narration consists of audio recordings of text built into an application. The most compelling potential benefit of audio narration is that it scaffolds learning, such that children who cannot yet decode written text can interact with a book independently of an adult (Dore et al., 2018; O'Toole & Kannass, 2018). This is important because children are not always supervised by adults when using mobile digital devices (Marsh et al., 2015; Ofcom 2019) and also because many children learn languages not known to their parents (Dore et al., 2018). Five studies

Table 3. Papers included in the systematic review.

	Paper		Sample			Design			
Feature	Reference	Year	Country	Age	L1/ L2	Hardware	Social context	Activity	Outcomes
	Chaudhry	2014	Kuwait	9-10	L2	tablet & ipod	independent	e-book	Story comprehension; reading speed
	Dore et al	2018	USA	4-5	L1	tablet	independent / with parent	e-book	Story comprehension
	Ikeshita-Yamazoe et al	2012	Japan	4	L1	tablet	with parent	e-book	Engagement
	Li & Tong	2019	USA	9-11	L2	tablet	independent	flashcards	Vocabulary
Inbuilt narration	O'Toole & Kannass	2018	USA	4	L1	tablet	with experimenter	e-book	Story comprehension; word learning
Real-time conversation prompts	Boteanu et al	2016	USA	4-8	L1	tablet	with parent	e-book	Parent-child talk
	Troseth et al	2020	USA	3-5	L1	tablet	with parent	e-book	Parent-child talk; vocabulary; story comprehension
Interactive hotspots	Etta & Kirkorian	2019	USA	3-5	L1	tablet	with researcher	e-book	Story comprehension; word learning
	Piotrowski & Krcmar	2017	Netherlands	3-6	L1	tablet	independent	e-book	Story comprehension; engagement
Augmented reality	Cerezo et al	2019	Spain	4-5	L2	mobile	with peers	game	Pronunciation
	Chen	2020	Taiwan	11	L2	tablet	independent	videos	Vocabulary

included in the review addressed this feature (Chaudhry, 2014; Dore et al., 2018; Ikeshita-Yamazoe, Kiyono, Kawai, Kimura, & Yoshida, 2012; Li & Tong, 2019; O'Toole & Kannass, 2018). Four of the studies used e-books, and one used vocabulary flashcards.

Results differed depending on the child's age and on whether studies compared e-book narration with reading independently or reading with an adult. Compared to reading independently, 4 to 5-year-olds could retell more details from an illustrated book when using inbuilt narration (Dore et al., 2018). In this study, children read an age-appropriate storybook either independently or with inbuilt narration which activated automatically on each page. Children were subsequently tested on the number of events from the story they successfully retold and answered comprehension questions. Children who heard inbuilt narration performed significantly better on the retelling task and showed a trend towards better performance on the comprehension questions. For young children, therefore, inbuilt narration may help with understanding of narratives.

In another study, no evidence was found for inbuilt narration affecting story comprehension with older children. Chaudhry (2014) had 9 to 11-year-old children read an e-book using either the read-alone version or read-to-me function. In both versions, children could activate images to hear some of the words pronounced phonetically, but only the read-to-me function included full audio narration. When children were asked a series of retrieval and inference questions about the story, their performance was equivalent in both conditions. However, there are several plausible reasons for this null result: the study was underpowered ($n = 8$ per condition) and children's scores on the test approached ceiling. Furthermore, children in both conditions had access to hotspots, which could have compensated for the lack of inbuilt narration in the read-alone condition. Thus, it may be that older children derive little benefit from inbuilt narration when the text is at their reading level, but more evidence will be needed to explore this.

In the two studies discussed so far, inbuilt narration increased the speed of progression through the story, which may have both advantages and disadvantages for learning. Since comprehension was the same or better in these studies, inbuilt narration may be more efficient than independent reading (Chaudhry, 2014; Dore et al., 2018). But, faster reading may negatively impact children's learning of other elements of the text; for example, by reducing processing of print (Roy-Charland, Perron, Turgeon, Hoffman, & Chamberland, 2016). It should, however, be noted that the speed of reading may interact with the reading context and child age. Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, and Collins (2013) found that child-parent dyads reading in a more

naturalistic context spent *more* time reading electronic console books with narration and hotspots than an electronic console book with these features disabled. However, it is also possible that children with no print knowledge reading alone might skip more quickly through an e-book with only text compared to one with narration, as they would not be able to make sense of the text.

When inbuilt narration is compared with live adult narration, the impacts differ depending on whether adults read the text word-for-word or with elaboration. One study compared an adult reading the text word-for-word with inbuilt narration in terms of story comprehension and novel vocabulary learning for 4-year-olds (O'Toole & Kannass, 2018). They found that story comprehension was equivalent between conditions. However, inbuilt narration did lead to more novel vocabulary learning than an adult reading the book word-for-word. The authors suggested this could be because children in their sample perceived e-books to be a learning tool and therefore were more focused. It did not seem to be a novelty effect, as prior experience with tablet e-books did not mediate the effect. Conversely, in another study parents were asked to read an e-book to children in a natural way (Dore et al., 2018). This resulted in parents elaborating on the story and asking questions. In this condition, children's story comprehension and retelling were better than with inbuilt narration. Inbuilt narration therefore might promote equivalent story comprehension to hearing an adult read a text word-for-word but is not preferable to interactive shared reading. This is critical, because if inbuilt narration inhibits parents from engaging in dialogic reading techniques with their children (as some research suggests e.g. Parish-Morris et al., 2013) then any benefits for language skills could be negated.

Inbuilt narration may also be beneficial for word learning in a foreign language. In one study, English-speaking 9 to 11-year-olds were given flashcards for novel Chinese vocabulary: these either contained the written representation and a picture of the word, or a written, picture, and auditory pronunciation in Chinese (Li & Tong, 2019). Subsequent tests showed that including audio in the flashcards improved not only children's ability to link sound with the orthographic word form, but also their ability to link the orthographic form with the meaning. Whilst this is only one study, it suggests that including audio narration alongside visual and semantic representations of words may support memory for words.

Children's engagement may also be increased by inbuilt narration. In two studies, children's attention - measured by either physiological measures or observations of time spent looking at an e-book - was greater for inbuilt narration compared to a parent or adult reading the e-book

aloud for young children (Ikeshita-Yamazoe et al., 2012; O'Toole & Kannass, 2018). This suggests that children's learning behaviour is also affected by having inbuilt narration and could explain the identified benefit of inbuilt narration to novel word learning (O'Toole & Kannass, 2018).

In summary, inbuilt narration seems to enable children under 5 years to comprehend text better than reading alone and appears similarly effective to adult word-for-word narration. However, inbuilt narration seems to be less effective than co-reading with an adult when the adult expands upon the text. Inbuilt narration may also lead children to progress through a story more quickly; pay greater attention to the story; learn new foreign language vocabulary more effectively; and gain vocabulary in their first language, if children perceive the role of e-books as for learning. Future research could address the impact of inbuilt narration on early reading skills (e.g. phonological awareness and decoding). For example, studies using other technologies have suggested that inbuilt narration synchronised with highlighting of characters or phonemes might be beneficial to draw attention to matching letter forms and sounds (e.g. Shamir, Korat, & Fellah, 2012).

Real-time conversation prompts

Real-time conversation prompts are written or verbal suggestions for adults, delivered in the moment, which prompt further discussion with children on a topic. In the case of e-book apps, these prompts are based around the text. Examples of prompts used in the two studies reviewed here are given in Table 4. Prompts can promote story comprehension by focusing children on key information and providing an opportunity for children to express their understanding of the story and receive feedback. Including real-time prompts is also likely to benefit language learning through increasing the quantity and quality of parent-child talk. Parent-child talk is a strong predictor of children's language abilities, but not all parents naturally initiate high quality conversations with children around books (Troseth, Strouse, Flores, Stuckelman, & Russo Johnson, 2020). Indeed, higher order decontextualized language such as that promoted by distancing, inference and prediction prompts is especially lacking from unsupported parent input. Thus, having real-time suggestions for conversations about texts could provide opportunities for children to develop their oral language skills including vocabulary.

Parent-child talk can be enhanced when real-time conversation prompts are integrated into e-books. The quantity of parent-child talk was increased by prompts in studies with 4 to 8-year-olds (Boteanu, Chernova, Nunez, & Breazeal, 2016) and 3 to 5-year-olds

Table 4. Examples of real-time conversation prompts.

Prompt type	Description	Examples
Recall	Remembering details from the story	Why is Peg [the protagonist] excited? Who is taller, Peg or Cat?
Distancing	Linking events in the story to a child's real life experiences and knowledge	Who is the tallest in your family? An owl is a bird: what other birds do you know?
Inference & prediction	Using the text to make predictions and other inferences	How is Baby D [the protagonist] feeling right now? What will happen next?

(Troseth et al., 2020). The results of both studies showed an increase in the number of parent questions and conversational turns. Troseth et al. (2020) also found an impact on the number of words and lexical diversity for both parents and children, suggesting an increase in talk quality, and that parents generated many of their own original questions when prompts were made optional. Boteanu et al. (2016) found an impact of prompts on the number of combined child and adult utterances, but not the number of words or lexical diversity. Thus, the precise impact of prompts varies, though it is not clear to what extent this depends on the types of prompts used, how prompts are presented, the age of child, or other factors.

Despite increasing parent-child talk, there is no direct evidence that real-time conversation prompts for adults affect children's language learning. Conversation prompts did not have any immediate impact on children's story comprehension or vocabulary (Troseth et al., 2020). This null result could have been due to the measures created for the study not being sensitive to children's learning. Thus, further research will be needed to explore this question.

Boteanu et al. (2016) also found that effective conversation prompts can be sourced algorithmically from natural parent-child interactions. Prompts were extracted automatically based on previous real parent-child interactions and using modelling based on semantic graph topology (Boteanu et al., 2016). Automatically generated prompts were similarly effective to those generated by literacy experts, except that the expert's prompts generated more conversational turns (Boteanu et al., 2016). This suggests that with naturalistic data and the right computer models, good language prompts can be generated automatically which could be a useful way to implement prompts without requiring expert input.

In summary, the findings of these studies suggest that within an experimental context, real-time conversation prompts can help promote a higher quantity and quality of parent-child talk. There is no evidence yet that this immediately impacts children's comprehension or word learning from the story, although a review of research with e-books across different digital platforms suggested that including extratextual vocabulary questions

did improve children's vocabulary (Smeets & Bus, 2012). The long-term link between parent-child talk and language outcomes is also well established in other research, but future research should determine whether such prompts create the sustained increase in parent-child talk over time that might be needed to have an impact on children's oral language skills. Future research also needs to examine whether scaffolding the complexity of prompts for adults helps: Troseth at al (2020), presented simple prompts that appeared automatically on the first reading, followed by more complex prompts which were optional in a second reading, and many parents produced their own questions instead. It remains unclear which of these approaches is most effective for promoting comprehension and/or later language learning.

Interactive hotspots

Interactive hotspots are areas of a screen which can be touched by the child to initiate an event on the device (e.g. sound, word, or animation). According to the capacity model (Fisch, 2000), such hotspots are theorized to be either beneficial or detrimental to learning from a story depending on the information they provide. That is, they may provide similar information in a different modality, and thus be beneficial, or they may overload children with too much additional information (Piotrowski & Krcmar, 2017). The underlying assumption is that if children actively engage with learning through triggering hotspots, this may lead to more learning than only passively listening to a story.

The two studies identified in the review suggest that hotspots have minimal effect on children's story comprehension or learning behaviour (Etta & Kirkorian, 2019; Piotrowski & Krcmar, 2017). Etta and Kirkorian (2019) divided 3 to 5-year-old children into three groups. Children either: touched a relevant hotspot (a plot-relevant image) to progress to the next page of an e-book story; passively watched the experimenter touch the relevant hotspot; or touched an irrelevant hotspot (a plot-irrelevant image). These groups were all equivalent in terms of story comprehension and novel word learning, suggesting that including interactive hotspots had no effect on children's learning. Piotrowski and Krcmar (2017) assigned 3 to 6-year-old children to use an e-book either with the hotspots turned on or off. The hotspots activated animations of objects or characters. Story comprehension was again identical between groups. Children who used hotspots were rated by observers as paying less attention to the story, although observer's judgements may have been biased by an assumption that activating hotspots signifies reduced attention to the text. Thus, the two existing studies suggest limited impact of hotspots on story comprehension, learning behaviour, or word learning for young children. This is consistent with an earlier meta-analysis of all digital book formats

(including PC versions), which found that hotspots had a negative or no impact on children's story comprehension (Takacs et al., 2015).

However, the effectiveness of hotspots could depend on the learning goal, the type of action initiated by the hotspot, and possibly the contingency of activation. For instance, if the learning goal is word learning, including hotspots that attract attention to the word of interest, and definitions of the word, have been shown to support vocabulary learning with computer e-books (Smeets & Bus, 2015). The effectiveness of hotspots may also depend on how they are activated: a recent study examined the effect of contingency of hotspots on children's story comprehension. Specifically, animations of actions from the text activated only when the child read the related section of the text aloud. Story comprehension was better in this contingent condition compared to when the animations were not contingent on their behaviour (Eng, Tomasic, & Thiessen, 2020). In the study, contingency was implemented using a hybrid of app technology and manual activation, but if future technology can support such contingency, then this may enhance the effectiveness of hotspots.

Augmented reality

Augmented reality (AR) has been defined in diverse ways, but taken broadly refers to any experience in which virtual, context-sensitive information is dynamically overlaid with real-world contexts (Maas & Hughes, 2020; Wu, Lee, Chang, & Liang, 2013). In terms of mobile applications, this interaction can take place on-screen (such as when digital objects are superimposed over camera images of the real-time physical environment), or in the physical environment (for example through holographic projections of digital objects into physical space). There are suggestions that this technology can be motivating for children, due to its novelty in combining the physical and digital (Cerezo, Calderon, & Romero, 2019).

Two studies were identified in this review which were focused on AR with second language learners (Cerezo et al., 2019; Chen, 2020). One study examined Spanish-speaking 4 to 5-year-old children's learning of the pronunciation of English words through presentation in an app (Cerezo et al., 2019). The control version of the app provided animated depictions of the words to be learned (e.g. a swimming fish for the word *fish*) on screen. In the AR version of the app, the phone was used to project these animations as holograms onto a physical stage. Children's pronunciation of the words was assessed by their teacher. The results suggested that although children in both groups learnt to pronounce more words, children in the AR condition performed slightly better.

Children in this group were also more motivated, which could explain the difference in learning performance.

A secondy study suggested that implementing video-based learning in an AR interface may also have an impact on second language learning. Chen (2020) presented 11-year-old Taiwanese English as a Foreign Language (EFL) learners with video clips containing information about insects in English. In the AR condition, students scanned physical insect specimens and a video clip appeared adjacent to the specimen. In the control condition, students watched the same video clips without the AR component. Their knowledge of the English names of insects was assessed with 10 multiple-choice questions at pre-test and post-test. The results showed a significant but small effect of condition, such that the children in the AR-enhanced video condition performed better at post-test than the control group. Children in this group also reported higher intrinsic motivation, which again could explain the difference in learning performance.

Taken together, the two existing studies suggest a modest positive effect of AR on children's motivation and learning. However, it should be noted that both studies found small effect sizes for the benefit of AR, and assignment was conducted by class: thus teachers were not blind to condition and could have influenced the results. The studies both found an impact of AR on children's motivation, a finding supported by other studies not included in this review (e.g. Wu, 2019). Such motivational benefits are often not sustainable as children acclimatise to new technologies and the novelty effect wears off (Clark, 1983). Thus, studies of longer-term usage of these methods would be needed to assume a consistent benefit of AR to learning. AR could perhaps be used more effectively by linking the contextual sensitivity of this feature clearly to educational goals, for instance finding text in the physical environment.

Limitations of existing literature

The theoretical motivation and contribution of the studies reviewed is weak, as they draw upon only a handful of broad theoretical frameworks to position their predictions and findings. Most studies simply framed their motivation for the research in terms of the ubiquity of digital devices rather than a theoretical educational question. The main theoretical approaches cited were the capacity model of comprehension of educational television content (Fisch, 2000) and the cognitive theory of multimedia learning (Mayer, 2014). These theories were based on pre-touchscreen technologies and both propose that because the attentional system is limited and somewhat modality-specific, using multiple

modes of input (such as audio and visual) should enhance memory and processing. These theories were referenced in relation to hotspots and inbuilt audio narration (Li & Tong, 2019; Piotrowski & Krcmar, 2017). Motivational theories have also been applied, specifically to prompt a study on AR in vocabulary learning (Cerezo et al., 2019). The proposal that AR increases student motivation, and thereby learning, is reasonable but under-specified and less practically useful if motivation is dependent on the novelty of technologies (Clark, 1983) which is devalued over time. Conversely, in other domains (e.g. physics and ecology Enyedy, Danish, Delacruz, & Kumar, 2012; Kamarainen, Reilly, Metcalf, Grotzer, & Dede, 2018) more precise predictions about the benefits of AR for visualization in space or revealing hidden aspects of ecosystems have been devised and borne out in research. Thus, there is a mismatch between the specificity of the experiments reviewed here and the theoretical basis and insights generated.

The lack of theorizing around linking specific features of apps to specific learning goals is surprising given the volume of qualitative research which could be used to generate hypotheses. A large qualitative literature exists, based on observational and interview methods, which provides suggestive indications of how children use app features in language learning (Baker, 2017; Falloon, 2013; Fantozzi et al., 2018; Hutchison, Beschorner, & Schmidt-Crawford, 2012; Levinson & Barron, 2018; Mogyorodi et al., 2019; Terantino, 2016; Wang et al., 2020). For example, Wang et al. (2020) suggested that good comprehenders may use app features in different ways to poor comprehenders, such as repetition of narration. Similarly, Levinson and Barron (2018) noted that parents of children who were not native English speakers used repetition of words to support their own pronunciation and vocabulary. This literature could be drawn upon to generate precise hypotheses about links between specific features of apps and specific learning outcomes. Subsequent studies would provide theory-driven evidence with real value for instructional design.

Aside from the theoretical limitations of the reviewed research, the paucity of studies identified by this review is worthy of note. In particular, there is a lack of research on language learning outcomes outside of story comprehension and single-word vocabulary learning: for example, no studies were identified which examined essential skills of grammar, writing, spelling, phonological awareness, or decoding. Furthermore, there is a notable absence of a range of features of mobile touchscreen applications, and specifically more technologically advanced features. Studies with other features were excluded from the review because they were qualitative or did not isolate specific features of apps to identify causal impacts. For example, there are some studies on QR codes (Arikan

& Ozen, 2015), translation services (Rivera Pérez et al., 2019), video chat on mobile devices (Waldmann & Sullivan, 2019), and speech recognition (Baker, 2017) which could not be included. It will not be possible to ascertain the learning potential of such new technologies without carefully controlled, theoretically driven studies. There was also a lack of included studies focussed on games, despite the popularity of games as a tool for teaching language (Bhide et al., 2019; Duh, Koceska, & Koceski, 2017; Samur, 2019). Thus, there are many gaps in the extant literature which are open to be addressed in future research.

Discussion

This systematic review synthesizes the research on links between specific features of mobile, touchscreen devices and language learning in children. By focusing on experimental and quasi-experimental studies which manipulated specific features of mobile, touchscreen devices, we targeted only the strongest evidence for a causal impact of app features on language learning. The review offers significant insights in this new and growing area of inquiry and provides a vital foundation for future research.

The review provides insights into the effects of four features of mobile applications on children's language learning, which have implications for educators and educational app designers. In the case of inbuilt narration, the literature suggests that it can be beneficial for reading comprehension for children who are just beginning to read, which is consistent with previously identified benefits of multimedia in e-books (Takacs et al., 2015). However, there is no evidence of a benefit to older readers. This suggests that inbuilt narration should be included in e-books for children under 6 years to aid comprehension, but that this may not be necessary for older children. Including auditory representations of words alongside written and semantic information appears to improve memory for words, and also helps to capture children's attention. Thus, including narration of vocabulary to be learnt is likely to be beneficial in apps for word learning. However, developers should be wary of possible downsides to inbuilt narration: in particular that it may speed up reading and reduce independence of reading for older children. Therefore, including scaffolds to remove narration as children become familiar with texts might be appropriate.

Conversation prompts for parents were found to be an effective feature of apps for language learning in the context of e-books within the studies in this review. Children learn better with a parent's elaborations than when simply reading word-for-word, and real-time conversation prompts for parents improved the quantity and quality of

parent-child talk around e-books. This is consistent with research with educational television (Strouse, O'Doherty, & Troseth, 2013) and traditional books (Mol, Bus, De Jong, & Smeets, 2008) which suggests that interventions that encourage parent-child conversation also promote child language outcomes. This finding is especially important given that in naturalistic interactions with digital toys and books without conversation prompts, content-related parent and child talk tends to be reduced in quantity and quality (Parish-Morris et al., 2013; Zosh et al., 2015). Apps would likely be more effective at developing vocabulary if they directly encourage parent-child conversations around texts, through making inbuilt narration optional and including conversation prompts.

Interactive hotspots were not overall effective at promoting story comprehension or word learning in the studies included in this review. Hotspots which progress a story or animate characters and scenes within the story had no impact on story comprehension or word learning when reading texts on mobile touchscreen devices. This suggests that it is not necessary to include hotspots in storybook apps, but also that relevant hotspots are not detrimental, unlike irrelevant hotspots which appear to reduce story comprehension in digital books (Takacs et al., 2015). However, hotspots that are contingent on children's verbalisations may promote comprehension (Eng et al., 2020) and so interactive hotspots may become more effective as technologies evolve.

The reviewed literature also suggests that augmented reality boosts student motivation and subsequent language learning when used to draw attention to new vocabulary. When animations or videos relating to words were presented in augmented reality for English second language learners, student's motivation was increased, and in turn word pronunciation and vocabulary learning improved. This suggests that including augmented reality components may boost language learning via increased motivation which could partially a novelty effect (Clark, 1983), where the benefit may decline with exposure to AR. This supports research from other age groups and domains which suggests a benefit of AR over other educational materials in terms of student's motivation and learning gains (Garzón & Acevedo, 2019).

Based on the findings of this review, we present some recommendations for future research studies and their dissemination in this important area of study. Many papers matched the keywords for the review, but few met the inclusion criteria. There are several reasons for this. Firstly, a lack of clarity in paper abstracts about important features of study designs, such as the age group, technology used, and domain of learning led to many papers being included initially. Secondly, many studies addressed a different research question to the present review, specifically

whether touchscreen technologies can support learning (e.g. the general efficacy of using iPads, or the impacts of interventions using a combination of several apps). Finally, many papers were not methodologically rigorous enough to be included, particularly failing to isolate single features by using inadequate control groups. Much of the existing literature then is still in the phase of identifying possible benefits of app usage, without specifying which design features are important. More effective dissemination of findings across discipline boundaries may help to steer the research towards novel questions and developing holistic theories.

This review has identified a number of gaps in the existing literature and provides a strong impetus for more quantitative research in this area. In general, there is significant opportunity to conduct theoretically informed experimental studies drawing upon existing qualitative studies (e.g. Fantozzi et al., 2018; Levinson & Barron, 2018; Wang et al., 2020). There is room for more nuanced theorising and hypothesis-testing relating to the impact of app features on language learning which can be sourced from existing qualitative work (Handley, 2014, 2018). More specifically, studies are needed to examine a wider range of features of applications (see Table 1), a greater variety of language skills (e.g. writing, reading, grammar), and the interaction between application features and learner characteristics such as age, language aptitude, language learnt (e.g. Chinese vs. Italian), and L1 vs. L2 learning (Kucirkova, 2019). For instance, the features needed to support vocabulary for a 3-year-old who has not yet learnt to read are likely to differ from those needed for an 11-year-old who is a fluent reader. There is a notable lack of research in this area with children, perhaps due to the greater challenges in recruitment and obtaining consent compared to adult learners, but these practical issues are easily resolved and should not prevent this important research from developing. Furthermore, educators could be more assertive in their role of shaping the design of future learning technology, as well as evaluating pre-existing technologies and programs. Through collaboration with technology researchers and app designers, more effective digital learning environments could be created to fulfil needs in the classroom and be evaluated rigorously.

One strength of the present review which could also be considered a limitation is the strict inclusion criterion with regard to study design which led to the exclusion of many studies. The small number of studies, and their diversity with respect to features such as language learnt, learning context, and child age, also limits the strength of the implications that can be drawn from the study findings, although this seems to be a reflection of the literature available. Some of the existing studies, despite having a rigorous design in line with our inclusion criteria, had

small sample sizes, reducing the reliability of their findings. Whilst the keywords were selected to be comprehensive, some relevant terms may still have been omitted (e.g. speaking, listening). The review also did not include grey literature, which could provide a different angle from published articles, although relatively few studies with the appropriate design are likely available in unpublished literature.

In conclusion, the literature reviewed here suggests that certain features of mobile touchscreen apps (such as inbuilt narration and real-time conversation prompts) are supportive of some aspects of language-learning, whilst others (interactive hotspots) have a limited effect or play a role through boosting motivation (such as AR). Aside from the important insights relating to these four features of apps, there is a dearth of experimental research on the impacts of features of apps in language learning. This lack of research contrasted with the ubiquity of mobile touchscreen apps should motivate future research in this area. This future research should build on learning theory, qualitative work, and hypothesized links between learning goals and features of applications. Such a programme of research would ensure that future technologies are effective tools for building children's language and literacy skills.

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The authors declare no conflicts of interest.

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