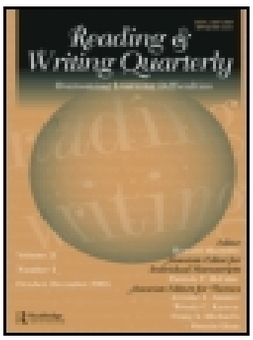

Routledge
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Reading & Writing Quarterly
Overcoming Learning Difficulties

ISSN: 1057-3569 (Print) 1521-0693 (Online) Journal homepage: https://www.tandfonline.com/loi/urwl20

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To cite this article: Elizabeth Swanson, Christy R. Austin, Alicia A. Stewart & Nancy Scammacca (2020): A Meta-Analysis Examining the Effect of E-Book Use on Literacy Outcomes for Students in Grades K–12, Reading & Writing Quarterly, DOI: 10.1080/10573569.2019.1696724

To link to this article: https://doi.org/10.1080/10573569.2019.1696724

Published online: 21 Jan 2020.

READING & WRITING QUARTERLY
https://doi.org/10.1080/10573569.2019.1696724

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A Meta-Analysis Examining the Effect of E-Book Use on Literacy Outcomes for Students in Grades K–12

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ABSTRACT

To better understand the impact of using e-books on students' reading outcomes, we conducted a meta-analysis of 14 studies with students in grades K–12 published between 2007 and 2018. Findings revealed an average effect size across all studies and reading outcomes of 0.9 that did not differ significantly from zero. There was also no statistically significant difference between e-book and non-e-book conditions on measures of reading comprehension. While these findings present preliminary evidence that e-books may be a viable alternative to traditional print books for supporting students' reading comprehension development, reasons for interpreting these findings with caution are presented.

In 2009, the International Reading Association (IRA, 2009) recommended integrating technology into reading programs in school settings. In addition, the majority of state standards require that students become proficient in navigating technology to support literacy development (Edyburn, 2004). These recommendations and state standards were likely developed to ensure alignment between classroom reading instruction and the multimodal formats of text reading that many children utilize outside of school on phones, computers, tablets, and game systems (Bearne, 2005). As a result of continuous technological advances to e-books over the years, today many e-books have the capability to feature portability, a built-in dictionary to support word meaning and phonetic pronunciations for unknown words, pictures and animation to support text-meaning, and adjustment of text size (Wilson, 2003). These technological advances could potentially provide educators with a way to accommodate, differentiate, and individualize to support students with diverse learning needs (Eagleton & Dobler, 2007).

The use of e-books in classroom settings is still relatively new and their use is still considered a novelty in most classrooms (Embong, Noor, Hashim, Ali, & Shaari, 2012). However, e-book usage is on the rise in classroom settings, due to both cost efficiency and ease of use. Publishers offer e-book alternatives that are often cheaper than print books. In addition, e-books are easily integrated into existing reading programs and instruction (Zucker, Moody, & McKenna, 2009). For this reason, many schools adopt e-books with the assumption that students learn equally well from print and electronic text. Until recently, however, little has been known about the effects of using electronic text compared to print text. Therefore, it is imperative to allow scientific research to guide the conclusions drawn regarding the effects of electronic book (e-book) instruction on the reading outcomes of students in grades K–12.

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What is an E-Book?

The term "e-book" was first coined by Andres van Dam in 1967 to refer to text from a book that was presented in electronic form on a computer, rather than printed on paper (Anuradha & Usha, 2006). Research on e-books has demonstrated that the term has been broadly defined and has been used to refer to a variety of digital features, with no universal definition of what constitutes an e-book and what does not across studies (de Jong & Bus, 2002; Korat & Shamir, 2004). For the purpose of this meta-analysis, we define an e-book as any form of electronic text that contains key features of print books, either narrative or expository. This synthesis includes both traditional e-books and enhanced e-books. Traditional e-books are digital versions of regular books that are read on an electronic device and are similar to paper-based books in terms of content and functionality. Enhanced e-books also include electronic text that contains the key features of print books but contain additional audio, video, or interactive content as well. This definition of an e-book excludes a variety of other technological software that can also support literacy development. For example, computer-assisted instruction software includes instructional activities that often contain electronic text reading, but the text reading is not embedded in a book format. These types of software programs were excluded from the meta-analysis on the basis of not containing the key features of traditional print books.

Prior research examining the effects of e-books on students' reading outcomes

Two prior syntheses were conducted examining the effects of e-book use on students' reading outcomes (Salmon, 2014; Zucker et al., 2009). Zucker et al. (2009) synthesized experimental and quasi-experimental studies investigating the effects of e-book use on pre-kindergarten to fifth-grade students' reading comprehension and decoding outcomes. Findings from seven randomized controlled trials demonstrated small to moderate effect sizes of e-books on reading comprehension (average effect $d = 0.41$). Only two studies examined the effects of e-books on decoding. One study (de Jong & Bus, 2002) indicated a negative effect ($d = -0.18$) of e-books on decoding outcomes, while the other study (Talley, Lancy, & Lee, 1997) demonstrated a small effect ($d = 0.19$) of e-books on decoding outcomes.

Salmon (2014) conducted a narrative review of studies examining the factors that affect the potential efficacy of e-books to support the literacy development of children in prekindergarten through grade one. In order to synthesize the findings related to the quality of software and interactive features, Salmon (2014) compared studies that examined the quality of commercially-available e-books to the quality of e-books developed by researchers examining the effects of e-books on a variety of student reading outcomes. Few commercially-available e-books included interactive features that either supported literacy skill development or the storylines of e-books, instead of including unrelated animation. In contrast, experimental and quasi-experimental studies investigating enhanced e-books designed by researchers frequently utilized interactive features that were highly aligned to the literacy skills and stories led to significant gains in the listening comprehension skills of students in early childhood. Salmon (2014) also reported that repeated reading of e-books led to greater gains in vocabulary and phonological awareness. Finally, findings from the Salmon (2014) synthesis suggest that e-book usage is not a substitute for reading instruction or adult interaction. Several studies included in this synthesis demonstrate that e-book usage including a trained adult prompting students to engage appropriately with the electronic text and discussing the story with students had a positive effect on students' listening and reading comprehension outcomes.

Findings from prior syntheses indicate that the use of e-books may have a small to moderate effect on reading comprehension. However, conclusions related to e-book efficacy on other reading outcomes (e.g., decoding and vocabulary) were not possible given the small number of studies

($n = 7$; Zucker et al., 2009) that provided enough information to calculate effect sizes. They also provide information about trends in prior research related to e-book design. However, results from the Salmon (2014) synthesis do not explore how these design features are related to student outcomes. Our work updates and extends the work of the two prior syntheses. First, the current meta-analysis extends the search beyond 2007 (as in Zucker et al., 2009) and 2013 (As in Salmon, 2014). We included studies through 2018, which we view as important given the increase in use of e-books in classroom settings and the increase in research conducted investigating the effects of e-books. Second, Zucker et al. (2009) conducted a meta-analysis of seven studies, and Salmon (2014) conducted a narrative review. We extended the work by conducting a meta-analysis of a greater number of studies. This allows us to employ more rigorous meta-analytic techniques than those used in the prior meta-analysis (Zucker et al., 2009). Finally, prior work focused on preschool and elementary school. We extended the search to include studies that investigated the effects of e-books for students in kindergarten to grade 12. The research question addressed is: What is the effect of e-book reading on the reading outcomes of students in kindergarten through twelfth grade?

Method

Data collection

We conducted a comprehensive search of the literature based on guidelines recommended by Cooper (2017). We utilized four major databases: (1) Academic Search Complete, (2) Education Source, (3) ERIC, and 4) PsychINFO. Databases were searched in the effort of locating all studies published between January 2006 and October of 2018 that included e-books within the independent variable. Search terms included electronic book, e-book, e book, eStorybook, digital book, CD-ROM book, multimedia book, media book, interactive book, interactive storybook, e-literature, e literature, talking book and literacy, reading, reading comprehension, vocabulary, decoding, phonics.

The meta-analysis included studies that met the following inclusion criteria:

a. Study designs using experimental or quasi-experimental design were included. Findings from these study designs contain both treatment and comparison groups—a feature necessary for calculating the impact of e-book treatments. Studies using qualitative designs, single-group designs, and crossover designs were excluded.
b. Studies using an independent variable including an e-book condition in which any interactive book was used (e.g., storybook, interactive CD-ROM, touch-screen book, any book described as an e-book) were included. Any studies that included audio books without the presence of visual support within a text, such as an interactive book, were excluded. In addition, studies in which the primary language used to deliver instruction was English were included. Any studies in which the intervention (i.e., e-book use) was delivered in languages other than English (e.g., 8 studies in Hebrew, 5 studies in Dutch, 1 study in Chinese, 1 study in Taiwanese) were excluded. In addition, we included studies that employed instruction in all settings (e.g., school, home, tutoring center, etc.).
c. We included studies measuring dependent variables that focused on reading outcomes (e.g., phonemic awareness, decoding, word reading, fluency, vocabulary, reading comprehension).
d. Studies including participants in grades K–12 were included. Studies including any participants outside these parameters had to include a minimum of 50% of students in the designated grades to be included. Studies that did not report information needed to calculate a minimum of 50% or those that did not disaggregate students by grade were excluded.
e. We included studies with at least 10 students per group. This eliminated one study, Coyne, Pisha, Dalton, Zeph, and Smith (2012), from the group of studies. In addition, we excluded studies that did not report data needed to calculate effect sizes (e.g., Wood, Pillinger, & Jackson, 2010).

The initial search yielded 3,094 articles. After importing abstracts using Zotero and removing duplicates, 2,099 studies remained. Prior to sorting abstracts, three independent researchers sorted 100 randomly selected abstracts into three folders: (1) yes (i.e., abstract contained information in full alignment with inclusion criteria), (2) no (i.e., abstract contained information that was misaligned with one or more inclusion criteria), and (3) maybe (i.e., the abstract contained incomplete information; these abstracts were placed in a "maybe" folder to prompt full text review). Coders reached an initial interrater reliability of 92% on the initial sort. Any discrepancies were resolved by coders, resulting in 100% agreement. After sorting all remaining abstracts, 57 studies remained in the 'yes' and 'maybe' folders. Next, authors conducted a full-text review of the 57 remaining articles, resulting in a final sample of 14 studies that met inclusion criteria.

Last, aligned with White's guidance on literature searches for meta-analysis (2009), authors conducted a hand search of 2018 issues printed by a small, focused set of journals known for publishing research related to education technology. Journals included: *Computers and Education, Journal of Educational Computing Research, Journal of Educational Multimedia and Hypermedia, Journal of Research in Technology in Education*. We also hand searched two journals that publish reading intervention research. Journals included *Journal of Literacy Research* and *Reading Research Quarterly*. No additional studies beyond those located during the electronic search were identified. A PRISMA flowchart is contained in Figure 1 (Moher, Liberati, Tetzlaff, Altman, The PRISMA Group, 2009).

Data analysis

Coding Procedures

All studies were coded using a codesheet adapted from the Vaughn, Elbaum, Wanzek, Scammacca, and Walker (2014) codesheet that was designed to align with the study features detailed in the What Works Clearinghouse (WWC) Design and Implementation Assessment Device (Valentine & Cooper, 2008). We adapted the codesheet to accommodate our focus on e-books. To do this, we included codes for information specific to e-book use (e.g., device used to access e-book, instruction on software/hardware, etc.). Studies were independently coded by three researchers. Prior to coding, interrater reliability was calculated by dividing the number of agreements by the total number of possible responses on the code sheet. Researchers reached initial interrater reliability of 96%. Studies were double coded to ensure consistent, reliable codes across all included articles. Discrepant codes were resolved with support from the lead author, who served as the Gold Standard (Gwet, 2001).

Effect size calculation

Standardized mean difference effect sizes were computed as Hedges's g based on the means, standard deviations, and group sizes for the treatment and comparison groups. Comprehensive Meta Analysis (Version 3.3.070) software (Borenstein, Hedges, Higgins, & Rothstein, 2013) was used to calculate the effect sizes.

Meta-Analysis procedures

Of the 14 studies included in the meta-analysis, 13 contributed more than one effect size as a result of using multiple outcome measures or comparing more than one pair of conditions (i.e., multiple treatments and/or multiple comparison groups), resulting in a total of 88 effect sizes for the analysis. When multiple effect sizes come from the same study, they are dependent (or correlated). In order for the results of the meta-analysis to provide unbiased estimates of the mean effect size and its standard error, this correlation must be accounted for in the meta-analytic

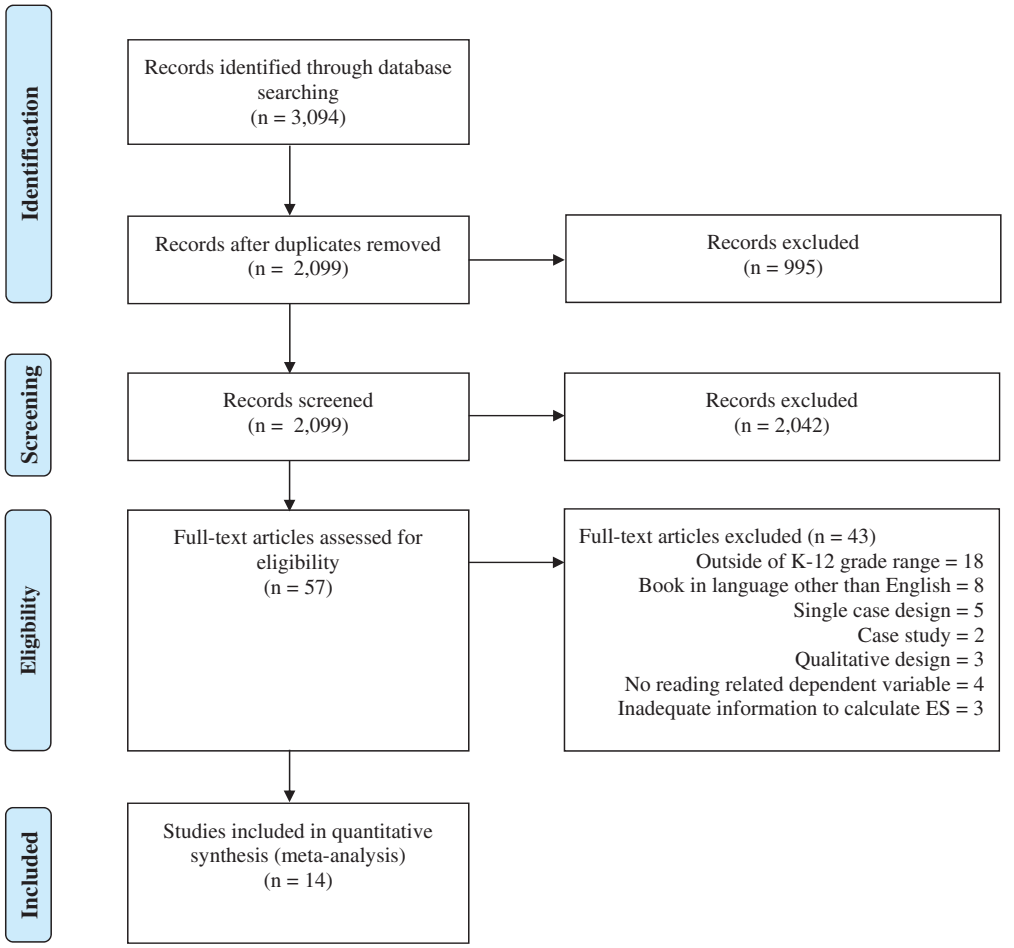

Figure 1. Prisma chart describing the search and inclusion procedures (Moher et al., 2009).

model. However, study manuscripts rarely include the observed correlation coefficients between measures. One solution to accounting for the dependency in the meta-analytic datasets is robust variance estimation (RVE; Hedges, Tipton, & Johnson, 2010). RVE adjusts the standard errors within a meta-regression model to reflect the correlated nature of effect sizes within studies included in the analysis.

RVE was implemented using the *robumeta* package for R (Fisher & Tipton, 2015) to calculate beta coefficients, mean effect sizes, and standard errors. Because the number of studies in this meta-analysis was less than 40, we implemented the small-sample correction in the model as a means of avoiding inflated Type I error (Tipton, 2015; Tipton & Pustejovsky, 2015). Although the observed correlations between effect sizes within studies was not known, in RVE the mean within-study correlation between all pairs of effect sizes (ρ) must be specified to estimate study weights and calculate the variance between studies. Hedges et al. (2010) demonstrated that the value selected for ρ has a very small effect on the results and recommended testing the impact of varying the ρ values on the model parameters. In the present analysis, we tested .2, .5, and .8 as values for ρ and found trivial differences in results. We reported results below from the model where $\rho = .8$.

In conducting the analysis using robumeta, we first estimated an intercept-only model to determine the weighted mean effect size and standard error. Next, the two categorical moderators

were entered into the model as covariates to determine if effect sizes differed significantly between the two levels of each moderator variable. Because not all studies reported information for each covariate, two separate models were estimated with the studies that reported grade level ($k = 13$) and the number of sessions ($k = 12$). Grade level was coded 0 for studies involving students in kindergarten through Grade 3 ($k = 7$) and 1 for studies involving students in Grades 4–6 ($k = 7$). Number of sessions was coded 0 for studies that held one session ($k = 7$) and 1 for studies that held more than one session ($k = 5$).

Lastly, we conducted a separate analysis of the effect sizes from reading comprehension outcomes in the 12 studies that included these measures. These studies also contained multiple dependent effect sizes, with the 12 studies producing 50 total effect sizes. The weighted mean effect size and its standard error across the reading comprehension outcomes also were estimated using RVE.

Results

A total of 14 studies, all with treatment comparison designs, met criteria for inclusion in the meta-analysis. Six studies were conducted in the last five years (i.e., 2014–2018). The remaining eight were published between 2006 and 2013. Table 1 describes the key features of each study. Twelve studies were conducted at the elementary school level and two studies were conducted at the middle school level. Across all studies, the number of sessions ranged from 1 to 20. In eight studies, students participated in one session. Five studies reported the number of minutes per treatment session (range 15–75).

A total of 1,049 students were included across the 14 studies with study sizes ranging from 18 to 205 students. Authors of four studies reported their student sample being from lower or lower-middle socioeconomic status ($n = 290$ students). Two studies included students from the middle socioeconomic status ($n = 116$ students) and the remaining nine studies did not report the student sample socioeconomic status ($n = 643$ students). No study reported any students as having a disability or academic risk for difficulty.

Study design

Several features of study design are critical to establishing the internal validity of study findings (U.S. Department of Education, 2017). One is the use of randomization where each participant has an equal chance of being assigned into a treatment or non-treatment group. Random assignment helps to ensure that any differences between the groups are not systematic before the study begins. It also helps establish that the results are not vulnerable to confounding variables. See Table 2 for a summary of study features critical to internal validity. All 14 studies used a treatment comparison or multiple treatments design. Seven of them were experimental and seven were quasi-experimental. Of the seven studies using quasi-experimental designs, three employed matching procedures to ensure equivalence at baseline for treatment and comparison groups.

Another key component of internal validity is establishing evidence that the treatment was delivered as intended (i.e., fidelity). Fidelity data was reported in two studies. In the remaining 13 studies, there was no evidence that fidelity data was collected, and no fidelity data was reported.

Finally, the use of standardized measures is important to establish that any differences among participants on measures is not due to differences in administration procedures. Thirty-three measures examining word reading, vocabulary, letter name knowledge, letter sound knowledge, and reading comprehension were used across the 14 studies. Authors reported that 13 of these measures were standardized and 6 were not. For the remaining 14 measures, standardization information was not reported. Only one study (Ortlieb, Sargent, & Moreland, 2014) used random assignment, included fidelity data, and used standardized measures. Table 3 contains a report of effect sizes for all measures across all studies.

Table 1. Key features of studies.

Study	Sample Size	Grade	Age	Number of sessions	Number of minutes
Barnyak and McNelly (2016)	41	1–3	nr	1	nr
Brabham et al. (2006)	152	Kinder.	5Y 1M to 6Y 8M	20	nr
Brown (2016)	66	6	nr	nr	nr
Doty et al. (2001)	39	2	nr	1	nr
Grimshaw et al. (2007)	132	nr	9Y 9M to 11Y 2M	1	nr
Kao, Tsai, Liu, and Yang (2016)	40	4	nr	1	30
Karemaker et al. (2017)	90	nr	68–84 M	1	nr
Lewin (2000)	32	1	5–6 Y	20	15
Long and Szabo (2016)	50	5	nr	20	20
Maynard and Cheyne (2005)	60	Year 7[a]	11–12 Y	1	nr
Nayak and Sylva (2013)	205	Year 4[b]	9–10	8	35
Ortlieb et al. (2014)	58	4	nr	12	75
Ricci and Beal (2002)	66	1	nr	1	15–25
Trushell and Maitland (2005)	18	nr	T = mean 9.22 Y C = mean 9.07 Y	1	nr

Notes: [a]in England; [b]in China; nr: not reported; Y: years; M: months; T: treatment; C: comparison.

Table 2. Summary of study features critical to internal validity.

Study	Random assignment	Fidelity data	Standardized measures
Barnyak and McNelly (2016)	Student		
Brabham et al. (2006)	Class	X	
Brown (2016)	Class		X
Doty et al. (2001)	None		
Grimshaw et al. (2007)	None		
Kao et al. (2016)	None		
Karemaker et al. (2017)	School		
Lewin (2000)	None		X
Long and Szabo (2016)	Stratified; Student		X
Maynard and Cheyne (2005)	None		
Nayak and Sylva (2013)	Stratified; Student		X
Ortlieb et al. (2014)	Class	X	X
Ricci and Beal (2002)	Student		
Trushell and Maitland (2005)	None		
Total	8	2	5

Meta-analysis results

In the intercept-only meta-regression model, the weighted mean effect size across all 14 studies was 0.09 (SE = .11; 95% CI = −0.15, 0.33). As indicated by the confidence interval, the mean effect size was not statistically significantly different from zero. The I^2 estimate of the percentage of between-study heterogeneity not due to chance variation in effects was 81.54%, with a τ^2 estimate of the true variance in the population of effects of .38, indicating that there was considerable heterogeneity in the effects of the studies included in the analysis. Despite the finding of a non-significant weighted mean effect size, we tested the effect of grade level and number of sessions as moderators of the magnitude of effects due to a large amount of heterogeneity among the effect sizes. In the model with grade level as a covariate, results indicated that effect sizes did not vary to a statistically significant degree based on whether participants were in Grades K–3 or Grades 4–6 ($b = -0.09$, $SE = .27$, $p = .75$). The weighted mean effect sizes for the seven studies involving students in Grades K–3 (0.13, $SE = .10$, 95% CI = −0.11, 0.36) and the six studies involving students in Grades 4–6 (0.04, $SE = .25$, 95% CI = −0.60, 0.68) did not differ significantly from zero. In the model with number of sessions as the covariate, effect sizes from studies involving one session did not differ significantly from those from studies with more than one session ($b = -0.27$, $SE = .23$, $p = .28$). The weighted mean effect size from the seven studies with one session (0.19, $SE = .21$, 95% CI = −0.33, 0.71) and that from the five studies with more than one session (−0.07, $SE = .09$, 95% CI = −0.33, 0.19) did not differ significantly from zero.

Table 3. Summary of e-book study findings with effect sizes.

Study design and e-book use	Measures	Findings
Barnyak and McNelly (2016) • T (Work alone with e-book) Orientation on how to use the software; students engaged with e-book as many times as they liked during the session. • C1 (Work with teacher and print book) Teacher led instruction that included reviewing front and back cover to predict story, activate background knowledge, a review of pictures, pre-teach "tricky" words, student read text aloud with teacher support and retold the story. • C2 (No treatment)	Word reading	T vs. C2 ES = −.11 T vs. C1 ES = −.56 C1 vs. C2 ES = .74
Brabham et al. (2006) • T1 (Meaning focused CD-ROM) Teacher read alouds of 10 alphabet books and focused on meanings of words + daily center time with CD-ROM of Dr. Seuss's ABC. • T2 (Phoneme focused CD-ROM) Teacher read alouds of 10 alphabet books and focused on sounds of letters + daily center time with CD-ROM of Dr. Seuss's ABC. • C1 (Meaning focused audio book) Teacher read alouds of 10 alphabet books and focused on meanings of words + daily center time with audio recording of Dr. Seuss's ABC. • C2 (Phoneme focused audio book) Teacher read alouds of 10 alphabet books and focused on sounds of letters + daily center time with audio recording of Dr. Seuss's ABC.	Vocabulary	T1 vs. T2 ES = .00 T1 vs. C1 ES = −.09 T1 vs. C2 ES = −.02 T2 vs. C1 ES = −.09 T2 vs. C2 ES = −.02
	Letter name knowledge	T1 vs. T2 ES = −.11 T1 vs. C1 ES = −.41 T1 vs. C2 ES = −.34 T2 vs. C1 ES = −.26 T2 vs. C2 ES = −.22
	Identify phonemes	T1 vs. T2 ES = .25 T1 vs. C1 ES = .18 T1 vs. C2 ES = −.37 T2 vs. C1 ES = −.08 T2 vs. C2 ES = −.66
	Phonetic cue reading	T1 vs. T2 ES = .28 T1 vs. C1 ES = .16 T1 vs. C2 ES = .16 T2 vs. C1 ES = −.14 T2 vs. C2 ES = −.14
Brown (2016) • T (e-book) Reading materials in English Language Arts were read via tablet. • C (no e-books) Reading materials in English Language Arts were read via printed text.	CTP4-reading comprehension CTP4-vocabulary Lexile	T vs. C ES = .34 T vs. C ES = .47 T vs. C ES = .00
Doty et al. (2001) • T (e-book) Researcher demonstrated how to use the software. Students engaged with e-book and online dictionary individually followed by a retell and answering questions posed by researcher. • C (print book) Students read the text individually followed by a re-tell and answering questions posed by researcher.	Comprehension questions Oral retell	T vs. C ES = 1.12 T vs. C ES = −.09

(*continued*)

Table 3. Continued.

Study design and e-book use	Measures	Findings
Grimshaw et al. (2007) • T1 (Magicians of Caprona CD-ROM no narration) Researcher demonstrated the software. A short synopsis of the story was read to the child. The child was allowed to the use the e-book and online dictionary. There was no audio played. • T2 (The Little Prince CD-ROM with narration) Researcher demonstrated the software. A short synopsis of the story was read to the child. The child was allowed to the use the e-book and online narration. There was no dictionary feature. • T3 (The Little Prince CD-ROM no narration) Researcher demonstrated the software. A short synopsis of the story was read to the child. The child was allowed to the use the e-book and no narration. There was no dictionary feature. • C1 (Magicians of Caprona print book) A short synopsis of the story was read to the child. The child was allowed to the read the print book. A print dictionary was provided. • C2 (The Little Prince print book) A short synopsis of the story was read to the child. The child was allowed to the read the print book.	Comprehension test	T1 vs. T2 ES = −.17 T1 vs. T3 ES = .47 T1 vs. C1 ES = −.35 T1 vs. C2 ES = .35 T2 vs. T3 ES = T2 vs. C1 ES = −.18 T2 vs. C2 ES = .54 T3 vs. C1 ES = −.87 T3 vs. C2 ES = −.13
Kao et al. (2016) • T1 (E-book low interaction) Narration and simple interactive buttons (previous page, next page, content menu); Hints given for comprehension questions are descriptive. • T2 (E-book high interaction) Narration and additional interactive buttons (previous page, next page, content menu, guidance [related information], prompt [question to enhance thinking], and feedback [after answering questions, tells student if it was correct or incorrect and provides additional information]).	Inferential story comprehension Critical story comprehension Literal story comprehension	T1 vs. T2 ES = −.41 T1 vs. T2 ES = −.92 T1 vs. T2 ES = −1.08
Karemaker et al. (2017) • T1 (Flat e-book) E-book contained illustrations and text. No audio, highlighting or animations. • T2 (E-friend e-book with pop up guide) e-book with no audio plus a dictionary feature and an e-friend feature that when clicked opened separate window where the e-friend asked a question about the story. • T3 (Interactive e book with dictionary) E-book with limited audio. Child could click on a word for the pronunciation or to activate the dictionary feature.	Comprehension Vocabulary Recall Target word reading	T1 vs. T2 ES = −.38 T1 vs. T3 ES = .22 T2 vs. T3 ES = .60 T1 vs. T2 ES = .44 T1 vs. T3 ES = .24 T2 vs. T3 ES = −.21 T1 vs. T2 ES = .19 T1 vs. T3 ES = .58 T2 vs. T3 ES = .41 T1 vs. T2 ES = .51 T1 vs. T3 ES = .36 T2 vs. T3 ES = −.23
Lewin (2000) • T1 (Enhanced e-book) Interactive e-book with word pronunciation when a word was clicked and hints for sounding out words (use the initial sound, illustration, meaning, or syntax). Students were told to read the story in its entirety and then to read each page and do one activity on each page.	Burt word reading test Common words test Key word test Phonic knowledge	T1 vs. T2 ES = −.09 T1 vs. T2 ES = .00 T1 vs. T2 ES = 0.20 T1 vs. T2 ES = .16

(*continued*)

Table 3. Continued.

Study design and e-book use	Measures	Findings
• T2 (Basic e-book) Students read the story on computer with no enhancement.	Salford sentence reading test	T1 vs. T2 ES = −.04
Long and Szabo (2016)	Gates macginitie	T vs. C
• T (Guided reading + e reader) Text reading in the small group setting where the teacher introduced the text to build background knowledge and then supported students as they read a variety of texts. All texts were presented on an e reader.	reading test	ES = .11
• C (Guided reading + print text) Text reading in the small group setting where the teacher introduced the text to build background knowledge and then supported students as they read a variety of texts. All texts were in print format.		
Maynard and Cheyne (2005)	Group comprehension test	T vs. C ES = 1.53
• T (CD-ROM) Interactive software containing text, animation, graphics and sound. Glossary is provided for terms. There is a variety of activities, assignments, quizzes, and web links.	Individual comprehension test	T vs. C ES = .42
• C (print text) Print version of the same book.		
Nayak and Sylva (2013)	NARA II Accuracy	T vs. C1 ES = −.07
• T (E-book) Text on screen accompanied by audio and activities after they finished reading. Students could click on a word for pronunciation and a series of word, sentence, and text level activities were completed after reading.		T vs. C2 ES = −.11
	NARA II comprehension	T vs. C1 ES = .21
• C1 (Guided Reading) Text reading in the small group setting where the teacher introduced the text to build background knowledge and then supported students as they read a variety of texts.		T vs. C2 ES = .23
• C2 (No Treatment)		
Ortlieb et al. (2014)	Basic reading inventory	T1 vs. C ES = −2.55
• T1 (My-ON) Students read and interact with digital texts based on their interest and reading comprehension level via an online reading environment. Students read digital books from recommended list followed by a comprehension test. Students receive more difficult books as they master 5 texts at each level. Software included text to speech capabilities, dictionary function, and embedded illustrations.		T2 vs. C ES = .23
	Lexile	T1 vs. C ES = .98
• T2 (Hybrid) Students use both traditional printed texts and the myON digital reading environment within one-on-one tutoring sessions. Students split their time equally be- tween both instructional formats while using comprehension strategies.		T2 vs. C ES = Not enough
• C (Print based instruction) Students use traditional, printed texts on their instructional level while learning comprehension strategies to foster reading improvement. information to calculate		
Ricci and Beal (2002)	Factual comprehension questions	T1 vs. T2 ES = .21
• T1 (E-book passive) Students listened to a recording and saw the e-book images for story.		T1 vs. T3 ES = .07
• T2 (E-book interactive) Students interacted with e-book that included audio, buttons to click to next page, and objects that provided special effects.		T1 vs. C ES = 1.08
• T3 (E-book yoked to interactive) Student watched on a separate screen as a matched student engaged with the interactive e-book.		T2 vs. T3 ES = −.15
• C (Audio only) Students listened to a recording of the story.		T2 vs. C ES = 1.04
		T3 vs. C ES = 1.14

(*continued*)

Table 3. Continued.

Study design and e-book use	Measures	Findings
	Inference comprehension questions	T1 vs. T2 ES = .22 T1 vs. T3 ES = −.25 T1 vs. C ES = .90 T2 vs. T3 ES = −.46 T2 vs. C ES = .66 T3 vs. C ES = 1.13
	Retell	T1 vs. T2 ES = .39 T1 vs. T3 ES = .07 T1 vs. C ES = .61 T2 vs. T3 ES = −.27 T2 vs. C ES = .26 T3 vs. C ES = .47
Trushell and Maitland (2005) • T1 (E-book interactive) Students interacted with e-book that included audio, buttons to click to next page, ad objects that provided special effects. • T2 (E-book passive) Students listened to a recording and saw the e-book images for story.	Comprehension	T1 vs. T2 ES = 1.0
	Story retell	T1 vs. T2 ES = −1.28

Note. T: treatment group; T1, T2, etc.: first, second, etc. treatment groups; C: comparison group; CTP-4: Comprehensive Testing Program-4; NARA: Neale Analysis of Reading Ability.

Effect on Reading Comprehension

Twelve studies included reading comprehension outcomes. In the analysis of reading comprehension outcomes, the weighted mean effect size of 0.22 (SE = .14; 95% CI = −0.08, 0.53). The effect is in the direction of e-books but did not differ significantly from zero.

E-Book versus Print Book

Across studies, comparison groups engaged in different activities (i.e., print text, alternative forms of e-books, audio books, or no treatment). We were particularly interested in the seven studies that compared e-books to print book use and measured the effect on reading comprehension (Brown, 2016; Doty, Popplewell, & Byers, 2001; Grimshaw, Dungworth, McKnight, & Morris, 2007; Long & Szabo, 2016; Maynard & Cheyne, 2005; Nayak & Sylva, 2013; Ortlieb et al., 2014). In the meta-analysis of seven studies in which print and e-book conditions were contrasted, the weighted mean effect size was 0.33 (SE = .19; 95% CI = −0.14, 0.80) in favor of the e-book condition, but this effect did not differ significantly from zero.

Publication Bias

When unpublished studies are not included in a meta-analysis, publication bias is a potential threat to the validity of the results. Publication bias occurs when studies that do not find statistically significant treatment effects remain unpublished and unavailable for inclusion in the corpus of studies in the meta-analysis. Given that the results of this meta-analysis indicated that the

weighted mean effect size was not significantly different from zero, publication bias is not a meaningful concern.

Synthesis of studies by outcome

While there were a sufficient number of effect sizes across multiple studies to meta-analyze the effect of e-book use on comprehension outcomes, this was not the case for oral reading fluency, phonics, vocabulary, or word reading. Therefore, the results for these outcomes are synthesized below.

Oral Reading Fluency

Authors of two studies included an oral reading fluency outcome measure (Nayak & Sylva, 2013; Ortlieb et al., 2014) that produced four effect sizes. Nayak and Sylva (2013) used the NARA-II, a standardized measure of oral reading fluency. Students used an interactive e-book with text on screen accompanied by audio and activities after reading. When compared to guided reading in a small group setting, the effect size was $g = -0.07$ (in favor of guided reading) and when compared to a no treatment comparison group, the effect size was $g = 0.21$ (n favor of the interactive e-book). Ortlieb et al. (2014) compared e-books to print books and reported an effect size of $g = -2.55$ in favor of print books. However, when comparing a combination of e-books and print books in a hybrid condition to the print book condition, the effect was smaller (ES = 0.23) and in favor of the hybrid condition.

Phonics

Two studies reported 16 effect sizes (Brabham, Murray, & Bowden, 2006 contributed 15 effect sizes) for phonics measures with mixed effects ranging from $g = -0.66$ to 0.28. In the Brabham et al. (2006) study, teachers conducted read alouds of alphabet books and focused on either the meaning of vocabulary or the sounds of letters. Then, students either listened to an alphabet book on audio recorder or enhanced e-book. For students in the meaning-focused group, those who used the supplementary enhanced e-book outperformed those who used the supplementary audio recording (ES = 0.18) on a measure of phoneme identification. However, for students in the phoneme focused group, those who used the supplementary audio recording outperformed those who use the supplementary enhanced e-book (ES = −0.66) on a measure of phoneme identification. Lewin (2000) compared the use of an enhanced e-book to a basic e-book and reported that the enhanced e-book was more effective for developing phonics knowledge (ES = 0.16).

Vocabulary

In three studies (Brabham et al., 2006; Brown, 2016; Karemaker, Jelley, Clancy, & Sylva, 2017), authors reported nine effect sizes on vocabulary measures, ranging from $g = -.21$ to 0.48. The only study that included a standardized, norm-referenced measure (Brown, 2016) included 6th graders who were all assigned to English language arts classes that use the same curriculum. There was only one difference between the treatment and comparison groups. Treatment students used tablets to read all English language arts text via e-book. Comparison students used print text. On the CTP4-Vocabulary measure, students who used e-books outperformed their print book reading peers with an effect size of $g = 0.47$. To the contrary, students in kindergarten who used audio books to supplement teacher-led read alouds (Brabham et al., 2006) outperformed students who used an interactive e-book on CD-ROM to supplement teacher read alouds on researcher-developed measures of vocabulary included within the teacher read aloud. Karemaker

et al.'s study (2017) that included early elementary school students indicates that students in the two less interactive e-book conditions outperformed students in the more interactive e-book condition.

Word Reading

Only one study reported information to calculate an effect size on one measure of word reading (Barnyak & McNelly, 2016). Students who worked with the teacher using a print book outperformed both students who used an e-book on computer (ES = −0.56) or students in the no treatment group (ES = 0.74) on a researcher-developed measure of word reading. In addition, students in the no treatment group also outperformed students who used an e-book on computer on the same measure (ES = −0.11).

Synthesis of studies by comparison group type

In addition to the seven studies examined in the meta-analysis that compared e-book use to print book use, one study compared e-book use to audio books (Ricci & Beal, 2002). This study of 66, 1st graders contained one audio book comparison group compared to three treatment groups: (1) passive e-book where students listened to a recording and saw the e-book images for the story, (2) interactive e-book where interaction included audio, buttons to click to the next page, and objects that provided special effects, and (3) yoked e-book where a student watched on a separate screen as a matched student engaged with the interactive e-book. In each of these contrasts, authors examined students' ability to answer factual questions, inference questions and give a retell of the story. The effects on factual questions were all above 1.0 (Treatment 1 v Comparison = 1.08; Treatment 2 v Comparison = 1.04; Treatment 3 v Comparison = 1.14). The effects on inference questions were all above 0.66 (Treatment 1 v Comparison = 0.90; Treatment 2 v Comparison = 0.66; Treatment 3 v Comparison = 1.13). The effects on retell were all above 0.26 (Treatment 1 v Comparison = 0.61; Treatment 2 v Comparison = .26; Treatment 3 v Comparison = .47). All of these effects were in favor of the e-book conditions.

One study compared e-book use to no treatment (Nayak & Sylva, 2013). In this study of 205 nine and ten-year olds, students in the e-book condition outperformed students in the no treatment condition with an effect of 0.23. This effect is on a standardized, norm-referenced measure of reading comprehension.

Discussion

These meta-analytic findings are the most recent in an attempt to better understand the effects of e-book use on reading outcomes for students in grades K–12. E-books are being adopted at an increased pace during recent years and have been lauded for their impact on motivation (e.g., Ciampa, 2012; Morgan, 2013) and influence on innovative teaching techniques (e.g., Larson, 2010). However, very few studies and even fewer reviews (narrative review by Salmon, 2014; meta-analysis by Zucker et al., 2009) have been conducted for investigating the effects of e-book use on student reading outcomes. In fact, recently enough experimental and quasi-experimental studies have been conducted to facilitate meta-analyses that help us better understand the impact of e-books on reading outcomes.

The overall effect size of 0.09 on all reading outcomes combined is the first report of its kind (the prior meta-analysis [Zucker et al., 2009] reported average effects by outcome). This overall effect size was not statistically different from zero, meaning that within this corpus of studies, students in e-book conditions performed equally well on reading outcomes when compared to students in other comparison groups. However, one might expect effects to differ based on the type

of reading outcome. Therefore, we investigated the effect of e-book reading on reading comprehension. The effect size of 0.22 reported here is aligned with the small to medium effects reported by Zucker et al. (2009). The current study provides additional information that the effect on reading comprehension outcomes did not differ significantly from zero, meaning that there is no difference, on average, based on e-book use.

In Zucker et al.'s (2009) meta-analysis, they reported two effect sizes related to phonics that when averaged equaled zero. In the current meta-analysis, only two additional studies examined phonics outcomes with small effects (0.18 and 0.16). One additional study examined the related skill of word reading with small to large effects in favor of print book use. We found effects of e-book use on vocabulary outcomes to range from −0.21 to 0.48. Vocabulary effects were not reported by Zucker et al. (2009). There are not enough studies that include phonics or vocabulary outcomes to meta-analyze the results.

Another unique contribution of the current study is the examination of reading comprehension outcomes for students who used e-books compared to those who used print books. Results of the meta-analysis produced an effect size of 0.33, but this effect is not statistically different from zero. This effect is similar to the overall effect of the 12 studies that included comprehension outcomes across all comparison group types (0.22)—also not statistically different from zero. Based on these findings, it seems that students who read e-books perform equally well when compared to students who use print books on measures of reading comprehension. However, this conclusion should be interpreted with exceeding caution. There is a small corpus of seven studies contributing to these effects. In addition, many of these studies have very small sample sizes. In four of the seven contributing studies, the sample ranged from 39–58 students (See Table 1). In the other two studies with larger samples, there were multiple treatment and comparison groups (Grimshaw et al., 2007: 132 students assigned to 5 groups; Nayak & Sylva, 2013: 205 students assigned to 3 groups), providing an indication that even these studies used underpowered samples. Findings from under-powered studies are particularly vulnerable to a Type two error, where there is simply not enough power to detect a difference in group outcomes if such a difference does in fact exist. In these cases, we are left accepting that there are no group differences, but the reason is based on an inability to detect a difference that might very well be there if enough students were included in the sample. For this reason, before making final conclusions about the effect of e-books on reading comprehension, studies with well-powered samples must be conducted.

Because there was a large amount of heterogeneity among the effect sizes, we hoped that key moderators would explain these differences. Because of the limited number of studies that reported adequate information, we were limited to a small set of moderators—grade level and number of sessions. In both of these moderator analyses, the effect was not different from zero. This means that similar student outcomes were noted for e-book use versus non-e-book use among K–2nd graders and 3rd–5th graders. In addition, similar student outcomes were noted whether students received one session of e-book use or more than one session. Other moderators are of interest but simply could not be investigated. For example, we were interested in learning more about the difference in reading outcomes when students use narrative versus informational e-books, but so few studies reported the text type that we could not include the variable in analysis. We also considered investigating the role of the type of e-book (e.g., interactive e-book, static e-book, e-book with read aloud capabilities, etc.). Too few authors included enough information about the e-book type to enable analysis. For similar reasons, we could not examine other moderators (e.g., group size, number of minutes, number of books read).

Limitations and future research

Across studies, we noted that key features to ensure internal validity were missing. For example, random assignment was used in only 8 studies, fidelity data was reported in only two, and there was extensive use of non-standardized measures. Only one study included all three key features.

This poses a substantial problem for interpreting the findings from this set of studies. With a lack of fidelity data, it is not clear that the e-book or non-e-book conditions were delivered as intended. In addition, some effects that are solely reliant on researcher-developed measures may be inflated by the fact that these measures may be overly-aligned with the intervention itself. It is unclear that assessments were administered using the same procedures across conditions. This is imperative to prevent bias. Future studies should carefully plan to include all necessary components of high-quality experiments in order to provide rigorous, valid, and reliable findings to inform e-book use.

Another issue with this group of studies is the variability in the comparison groups. Some comparison groups utilized print text. Others used audio books, no treatment, or variations of e-books. However, it seems to us that the most important question is how outcomes for students compare when using e-books versus print books. Future research should hold all intervention components constant (e.g., group size, instructional components, role of teacher, time spent engaged in session, text type, text length, text difficulty, etc.) with the only difference being e-book or print book use in order to better understand whether outcomes are impacted by the type of text presentation.

Finally, no published studies investigated the effect of e-books on reading outcomes for important subgroups of students. For example, no study examined the effects of e-book use among students with disabilities—a group of students who are most often included in general education classrooms where e-books are used. Likewise, no studies examined the effects of e-book use in upper middle school and high school. This is a time in schooling when text-reading volume surges and the expectation to learn content from text increases. High-quality studies investigating the role of e-books among this age group are necessary to inform education practices.

Conclusion

Findings from this meta-analysis are promising in that they provide initial evidence that reading outcomes for students in grades K–6 may not differ when reading e-books or print books. However, findings should be interpreted with great caution given the studies' numerous areas of concern, such as threats to internal validity, lack of statistical power, and limited information provided about key features of the samples and methods. Additional research that aligns with high-quality research design standards conducted with older students and students with disabilities is warranted.

Funding

The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A150407 to the University of Texas at Austin. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education.

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