Stimulating preschoolers' early literacy development using educational technology: A systematic literature review

Research interest in the potential of educational technology to support young children as they learn to read has significantly increased during the last decades. These studies typically adopt a media comparison approach (comparing learning with one instructional medium vs. another instructional medium) or a value-added approach (comparing learning with a standard version vs. one with an added feature). We aimed to systematically review both types of studies on the effectiveness of educational technology for enhancing preschoolers' early literacy development. Our systematic search in four databases resulted in 67 studies eligible for inclusion. Our analyses addressed three research questions: (a) Is educational technology effective in stimulating preschoolers' early literacy development? (b) Which features of educational technology and its implementation are associated with its effectiveness? (c) Which child-related characteristics are associated with its effectiveness? Results show that the media comparison studies provide some evidence for the effectiveness of educational technology in early literacy instruction, but supported by medium to large effect sizes for only part of the studies. Moreover, features of educational technology and child-related characteristics were less frequently investigated, with a small number of studies per investigated feature or characteristic. The small number of studies and limited availability of effect sizes does not allow to draw strong evidence-based conclusions related to these research questions. Future studies are needed to deepen current insights into the effectiveness of educational technology for early literacy instruction, and especially the contribution of specific educational technology features and child-related characteristics to its effectiveness.

Keywords: early literacy; educational technology; preschool; effectiveness; media comparison; value added approach

1. Introduction

Reading competence, i.e., the ability to fluently read with understanding, generally referred to as a good mastery of reading comprehension, is a crucial aspect of education and daily life [1]. Reading comprehension consists of two major components: (1) word decoding or technical reading, and (2) linguistic comprehension, defined as a broad set of language skills including receptive and expressive vocabulary, grammatical skills and narrative skill (cf. simple view of reading) [123]. Prior to formal schooling, children already develop foundational competencies for their further reading development [2, 3]. Given the pivotal role of word decoding in children's reading development and (consequently) its central place in the first years of formal reading instruction, researchers intensively studied the foundational competencies for word decoding development [4-8, 124]. In alphabetic languages four foundational competencies for children's word decoding and, thus also, overall reading success (reading comprehension) are identified: phonological awareness, letter-sound knowledge, rapid automatized naming, and print awareness [4, 6, 124]. Despite the well-established importance of these core components, early literacy instruction is confronted with numerous challenges as it tends to be narrow and insufficient [9-11]. Throughout the years, there has been an increasing interest in the potential of educational technology to support early literacy instruction and stimulate preschoolers' early literacy development [12, 13]. In comparison with non-digital educational tools, educational technology offers specific affordances [14], including interactivity, adaptivity, and linked representations, which could provide additional learning opportunities and help in addressing common barriers in early literacy instruction. Researchers increasingly investigate the potential of educational

technology also for early literacy instruction, but a systematic and comprehensive review of these studies is currently missing. We aimed to address this gap by systematically reviewing the available empirical research on the effectiveness of educational technology in facilitating early literacy development in preschool classrooms.

1.1. Early literacy

Early literacy, or *emergent literacy*, develops before children receive formal reading instruction. It can be defined as young children's precursor knowledge, abilities, and attitudes related to later manifestations of conventional reading and writing [2, 5]. An ever-growing number of studies points to the pivotal role of phonological awareness, letter-sound knowledge, and rapid automatized naming as cognitive foundations for learning to read in alphabetic languages [4-8, 15, 16, 118, 124]. As discussed in Hjetland et al.'s systematic review [124], these early literacy components are key for children's fluent word decoding development and, therefore, provide the basis for their overall reading success (i.e., mastery of reading comprehension).

Phonological awareness involves the ability to identify and manipulate units of sounds that compose spoken words, including syllables and phonemes [3]. It can be assessed through tasks such as: rhyme matching (e.g., selecting the word that rhymes with "cat" from response alternatives "hat", "bar", and "can"), syllable blending (e.g., "What do you get when you say 'can'… 'dy' together?"), syllable deletion (e.g., saying "candy" without /dee/), phoneme isolation (e.g., "What is the first sound in 'hat'?"), and phoneme deletion (e.g., "hat" without /h/). Children's phonological awareness establishes the foundation for efficient grapheme-phoneme mapping [17].

Letter-sound knowledge refers to the understanding that letters in printed words (i.e., graphemes) map on to the smallest unit of sounds in spoken words (i.e., phonemes) [3, 118]. Knowledge of letter-sound correspondences provides children with the foundation to decode unfamiliar words by themselves on a letter-by-letter basis and demonstrates their visual-phonological learning (i.e., associating abstract shapes or letters with corresponding sounds) [4].

Rapid automatized naming (RAN) is the ability to rapidly and accurately name familiar pictures, colors, letters, or digits [4]. It involves the retrieval of "names" as phonological codes from long-term memory, a similar process that is needed also for word recognition [3, 18].

In addition to these three components, *print awareness* is also identified as pivotal for the acquisition of reading skills [5, 19]. It refers to children's sense of written language and its function even without having the ability to read [3]. For example, in English, children's print awareness involves understanding that print has meaning, recognizing the difference between print and pictures, knowing the order in which the pages of a book are read, and knowing that reading must be done from left to right and from the top to the bottom of the page [20]. Print awareness lays the foundation for understanding letter-sound correspondences [21].

The four above-mentioned components are identified as most important foundations for children's word decoding development, with unique and significant contributions to children's overall reading success [120, 121, 124]. Given their key role in children's early literacy and later reading development, it is important that preschool instruction focuses on these four core components. Unfortunately, preschool early literacy instruction is faced with practical barriers, such as ensuring appropriate teacher-to-child ratios that allow for individualized learning opportunities [3]. Previous studies also found that many preschool programs tend to provide insufficient and ineffective literacy experiences, as, for instance,

limited instructional time spent on engaging in literacy-related activities [9], scarce learning opportunities and a focus on only rhyming [10, 22]. Additionally, preschool teachers tend to make little use of support strategies to assist struggling learners [11].

1.2. Educational technology

The potential of educational technology to promote early literacy development has attracted the attention of researchers [12, 13]. *Educational technology*, defined as "a variety of electronic tools and applications that help deliver learning materials and support learning processes" [23], offers affordances that may not be possible with non-digital educational tools. These affordances, such as adaptivity, collaboration, and linked representations or modality, are characteristics and possibilities of technology that facilitate important learning opportunities for users [14, 24, 25]. For example, an e-book may have the feature of linked representations as it uses animated pictures and sounds to present a story or topic as opposed to a simple print presentation. Another educational game on a tablet may have features of interactivity and feedback as it requires the learners to tap the picture that corresponds to the audio recording of the word in parts (e.g., phoneme segments) and provides immediate feedback (i.e., correct versus incorrect response, with a short explanation of why the learner's input was correct or incorrect). According to Moreno and Mayer [26], this can promote meaningful knowledge construction by creating a multimodal learning environment that aims to maximize children's active processing of the educational materials and minimize cognitive load. This is also in line with learning theories suggesting that children learn best when experiences are active or "minds-on", engaging, meaningful, and socially interactive [27]. More concretely, while keeping in mind the weaknesses of early literacy instruction, educational technology has the potential to facilitate preschoolers' exposure to educational materials through carefully designed environments. These digital learning environments may accommodate children's diverse needs and abilities by providing repetitive yet diverse and individualized exercises that target their core competencies, scaffold their learning by including multimodal and adaptive features, and sustain their interest by incorporating educational concepts in the context of play. Taking into account the far from ideal teacher-to-child ratio and limited instruction time in preschool classrooms, these digital learning environments can provide all children powerful learning-supportive activities in the domain of early literacy.

To investigate its instructional effectiveness, empirical research on educational technology typically adopts a particular approach, which is related to Mayer's [28] distinction between the media comparison and the value-added approach. Studies using a *media comparison* approach compare learning with one instructional medium (e.g., touchscreen mobile device) against learning with another instructional medium (e.g., printed book). While research on learning and technology usually adheres to this approach, it is argued that differences in learning outcomes cannot be attributed to the instructional medium as such. Instead, it is the design and instructional method within the instructional medium that will determine learning [28, 29]. Thus, shifting the focus from media comparison to *value-added* research is needed. Studies adopting a value-added approach compare learning by means of the standard version of educational technology (e.g., non-adaptive tablet game) with learning via the enhanced version including additional instructional features or affordances of the same technology (e.g., adaptive tablet game). Aside from the design features of educational technology, several other elements have been identified to affect the impact of an educational technology especially when implemented in large-scale school settings. These other elements include child-related characteristics, referring to (a) specific child characteristics such as age or prior knowledge; (b) child-related environmental factors such as SES; and (c) intervention-

related activities of the child such as time spent in the intervention), and the level of support provided to learners when using the technology [14]. Researchers increasingly analyze the contribution of child-related characteristics and different implementation types of educational technology as well [e.g., 30], for example, by comparing a condition of implementation without versus with additional teacher scaffolding.

Although there is general enthusiasm for using educational technology in early childhood instruction, systematic reviews on the effectiveness of educational technology for early literacy development are missing. Existing reviews focus on the effectiveness of educational technology for a wider age range and investigate actual reading performance and/or the acquisition of other linguistic competencies such as vocabulary and comprehension [e.g., 23, 31, 32], or focus on specific groups of children such as children with autism [e.g., 33] and children with learning difficulties [e.g., 34]. The number of reviews related to early childhood literacy is very low, and these few reviews suffer from theoretical and methodological weaknesses. Concretely, the few early literacy reviews were not systematically conducted, included only a small part of the available studies on the matter at hand, and are now outdated considering the continuous and fast-paced evolutions in technology [e.g., 35, 36, 37]. The recent systematic literature reviews of Herodotou [38] and Griffith et al. [39] on the effectiveness of technology on young children's learning both remain limited with reference to scope, as they only included research on tablet applications and a small number of studies on early literacy. Moreover, none of the aforementioned early literacy reviews made an explicit distinction between media comparison and value-added studies, constraining the findings and major conclusions of these reviews.

1.3. The current study

To address these gaps in the current research literature, we aimed to conduct a systematic review on the effectiveness of educational technology in the domain of early literacy in preschool classrooms, with inclusion of also the most recently conducted studies and distinction between studies following a media comparison and value-added approach. We formulated three research questions: (1) Is educational technology effective in stimulating preschoolers' early literacy development in preschool classrooms? (2) Which features of educational technology and its implementation are associated with its effectiveness? (3) Which child-related characteristics are associated with its effectiveness?

2. Method

2.1. Literature search and selection process

To identify studies of interest, a systematic search was conducted in April 2023 by consulting four electronic databases: ERIC (Ovid), PsycArticles, PubMed, and Web of Science. These databases were chosen based on the suggestion of the Cochrane Library Handbook [40], and their relevance to the subject area of this review. The following search string was entered to browse each database: *[(preschool* OR kindergarten* OR ''early childhood'') AND (''education* technology'' OR digital* OR computer* OR electronic* OR "education* media" OR "digital media" OR ICT OR technology OR "information and communication* technology") AND (reading OR literacy OR "early literacy" OR "emergent literacy")]*.

In the first phase, 2397 records were obtained from the four databases and saved in the EndNote 20 reference management tool. The list of records was checked for duplicates, with 352 duplicates automatically removed by the software and 120 duplicates manually removed. This resulted in 1925 unique records. In the second phase, the title and abstract of these

records were screened for relevance using the following criteria (see Table 1): (a) intervention study, (b) focus on the domain of early literacy, (c) use of educational technology, (d) formal organization context, and (e) preschool level. The first author conducted the title and abstract screening for all 1925 records, and the last author conducted the title and abstract screening of a randomly selected sample of 193 articles (i.e., 10% of the records). An interrater agreement rate of more than 97% was achieved (agreement on 189 of the 193 articles); the disagreement on four articles was resolved after discussion. The second phase resulted in 120 reports sought for full-text retrieval. Eleven of these reports were not accessible to the authors. In the final phase, 109 full-text reports were read and assessed for eligibility by the first author on the basis of the same inclusion criteria, which resulted in a set of 64 reports. Three of these articles reported on more than one study, which resulted in the final total of 67 studies included in the current review [41-103]. An overview of the literature selection process is shown in Figure 1.

2.2. Data analysis

We adhered to a narrative approach to analyze the data, which is recommended when the studies are characterized by a large heterogeneity and variability in populations, interventions, outcomes, and study designs [39, 105, 122]. First, the description of the primary studies (i.e., studies included in the review) was organized into logical categories. Second, a within-study analysis, focusing on identifying and summarizing the relevant findings per study, was conducted. Finally, a cross-study synthesis was completed to provide an overall summary of the findings that consider issues in variability between studies.

Each primary study in the review was assigned a number to use as reference in the reporting. The final data for all primary studies are organized into the following categories (see Table 2): (1) descriptive information (language, study design, participants, approach, early literacy component, grouping structure, and duration of intervention), (2) details of intervention (activities in the educational technology and early literacy condition, and in the control condition), and (3) main findings per research question. Regarding the study approach, the primary studies were categorized as media comparison and/or value-added [28]. However, as argued by Girard and colleagues [106], studies on educational technology suffer from the "control group problem," which highlights the heterogeneity of conditions and ambiguity of the concept of "control group" applied by the authors in their studies.

Following the suggestion of Verbruggen and colleagues [30] that a fine-grained approach of dividing the large number of studies into smaller subcategories could help to address the heterogeneity of control groups among the included studies, we further distinguished among five different types of media comparison studies based on the comparison treatment in the control group. These subcategories were labeled either *A* to signify the use of an active control group which received an alternative treatment or *I-BAU* for an inactive or passive control group which did not receive an alternative treatment, i.e., studies describing the control condition involving regular program or business-as-usual (with I referring to Inactive and BAU to business-as-usual, together I-BAU). Subcategories with active control group were further labeled either *ET* to refer to the use of educational technology in the alternative treatment or *NET* to signify the use of non-technology as an alternative treatment. The active control group subcategories were also assigned either *EL* to denote that the alternative treatment was applied for the stimulation of early literacy or *NEL* to signify that the alternative treatment did not focus on the stimulation of early literacy. On the basis of these distinctions, we identified the following five subcategories of media comparison studies: (1) *A-ET/EL*, with an active control group given an alternative treatment using educational technology on early literacy; (2) *A-ET/NEL*, with an active control group that

received a different treatment using educational technology but no focus on early literacy; (3) *A-NET/EL*, with an active control group that received a non-technology treatment that focused on early literacy; (4) *A-NET/NEL*, with an active control group that received a non-technology treatment and did not focus on early literacy; and (5) *I-BAU*, with an inactive control group that did not receive a comparison treatment, or referring to regular preschool program or business-as-usual for the control group.

3. Results

3.1. Description of the primary studies

An overview of the 67 reviewed studies and their key characteristics is presented in Table 3. These studies were published from 1998 to 2023. Twenty-five studies were conducted in North-America, 22 in Asia, 15 in Europe, four in Oceania, and one in South-America. Eleven languages were included: 32 of the studies focused on the English language, 16 on Hebrew, seven on Dutch, three on Turkish, and two each on Italian and on Portuguese. Other languages included by one study each were Arabic, French, Indonesian, Norwegian, and Spanish.

Regarding study design [107], 27 of the 67 studies adopted a true experimental design, 36 followed a quasi-experimental design and four used a single-subject design. The total number of participants across studies is 9485. Twenty studies included fewer than 51 participants, 25 studies between 51 and 100, 10 studies between 101 and 150, two between 151 and 200, three between 201 and 250, and seven included more than 250 participants. More than half (67%) of the studies had fewer than 101 participants. In terms of study approach, 46 of the 67 studies adhered exclusively to a media comparison approach, six followed exclusively a value-added approach, and 15 used both approaches. It is important to note that some studies included multiple control conditions within the media comparison approach (e.g., both business-as-usual and active control group) and sometimes even used both media comparison and value-added approaches (e.g., comparison with business-as-usual as well as an optimized version of the same technology), resulting in multiple references to these studies in our findings.

In terms of early literacy components, 41 focused on the effect of educational technology on one particular component, whereas 26 investigated multiple components. Most studies (n = 59) addressed phonological awareness, 20 focused on letter-sound knowledge, 15 addressed print awareness, and one study investigated RAN. Finally, the duration of the intervention varied widely, ranging from only two sessions for the whole intervention to daily sessions for one school year. Likewise, the length of intervention sessions was diverse, ranging from 7 minutes to 90 minutes.

3.2. Narrative synthesis of the primary studies

The findings from the 67 studies are summarized in Table 4. We present the major findings per research question, complemented with effect sizes and concrete information from the studies. It is important to note that effect sizes were not available for 31 of the 67 studies (46% of the studies). The reported effect sizes mainly fell into the medium to large range (29 studies, 43% of the studies; only 7 studies small to medium effect sizes).

3.2.1. *RQ1: Is educational technology effective in stimulating preschoolers' early literacy development?*

To answer the first research question, we analyzed the findings of studies following a media comparison approach (n = 61). Overall, nearly half of these studies (n = 26) found a positive intervention effect with - when available - small to large effect sizes, indicating that the intervention with educational technology in the domain of early literacy was more effective than the control condition. Nineteen studies reported mixed findings: 18 studies found positive effects for some early literacy outcomes and no effects for other outcomes, and one study observed negative and no effects for different early literacy outcomes. Fourteen studies reported no significant differences between conditions, while two studies found that the intervention with educational technology was less effective than the control condition. We now discuss these findings in more detail, distinguishing between five subcategories of studies on the basis of the control group included in the studies.

Looking into the first subcategory of studies, studies including a control group defined as A-ET/EL (n = 8), it was found that the majority of these studies compared code-focused computer games (i.e., games primarily associated with decoding print) with meaning-focused computer games (i.e., games primarily associated with understanding what is read) [54, 57, 83, 87, 98], two compared code-focused computer games with narrative e-books [53, 98], and one compared synthetic phonics with analytic phonics activities from the same computer program [50]. Four reported a positive effect with medium to large effect sizes [53, 57, 83, 87] and one study reported a positive effect without effect size [54], together indicating that code-focused computer activities were more effective than meaning-focused applications in improving preschoolers' phonological awareness. However, two studies reported mixed findings [50, 99], noting that one application or set of digital activities was more favorable for some early literacy outcomes but not for other outcomes. For example, a study [99] found that a code-focused computer program had a significant positive medium effect on phonological awareness but not on letter-sound knowledge when compared to the narrative e-book condition. Furthermore, one study reported no significant differences in effects of digital letter and meaning-focused games on both letter-sound knowledge and phonological awareness [98].

In the second subcategory, A-ET/NEL (n = 6), the active control group that received a different treatment using educational technology did not focus on early literacy, but on mathematics (n = 3), science (n = 1), and a combination of early literacy and mathematics (n = 2). Only one of the studies found a positive effect with a medium effect size [43], pointing to a higher effectiveness of early literacy computer games on both print awareness and phonological awareness compared to a combination of literacy and mathematics-focused computer programs. Four studies reported mixed findings with positive medium effects for some outcomes and no effects for other outcomes [medium effect size: 69, 81; no effect size 61, 102]. Finally, one study did not find any difference in phonological awareness gains between the intervention group that used an early literacy software and the comparison group that used a mathematics-focused software [42].

In the third subcategory, A-NET/EL (n = 16), the studies utilized printed books (n = 8), oral storytelling (n = 1), pen-and-paper exercises (n = 1), and other non-digital activities targeting early literacy (n = 6) in the control condition. Of these studies, two reported a positive effect with medium to large effect sizes [47, 60] and three without effect sizes [59, 71, 75] in favor of the educational technology condition facilitating either phonological awareness, letter-sound knowledge, or print awareness. Four studies reported mixed findings: three found positive medium to large effects for some early literacy outcomes and no effects for others [63b, 68, 92], and one found negative effects and no effects for

different early literacy outcomes [67; medium effect size]. Five studies found no significant differences between conditions supported by small to medium effect sizes [51, 73, 101, 103] or without effect size support [64], and two studies reported that the intervention condition with educational technology was less effective than the control condition in stimulating phonological awareness and letter-sound knowledge respectively [44, 77]. Results from the A-NET/EL subcategory were contradictory. For example, in terms of facilitating print awareness, one study [59] suggested greater benefits from e-books than printed books but without reported of effect sizes, two studies [63b, 92] observed no significant differences between e-books and printed books with medium to large effect sizes, and one [67] found that printed books were more effective than e-books (medium effect size).

Concerning the fourth subcategory, A-NET/NEL, none of the included media comparison studies utilized this type of control group.

Finally, the fifth subcategory, I-BAU (n = 38), included an inactive control group that did not receive a comparison treatment during the study. This subcategory comprised the largest number of studies. Eighteen studies reported a positive effect, but only six studies supported these findings with medium to large effect sizes[46, 70, 84, 86, 92, 93] (no effect sizes or small effect size for studies [45, 48, 49, 55, 60, 62a, 75, 79, 85, 89, 94, 104]) suggesting that the intervention with educational technology was more beneficial for children's phonological awareness, letter-sound knowledge, and/or print awareness than the instruction offered in the inactive control condition. Eleven studies reported mixed findings with positive effects for some early literacy outcomes and no effects for others [62b, 66, 74a-b, 76, 78, 82, 91, 95-96, 102]. Another nine studies found no effects for any of the examined outcomes [41, 62, 64-65, 70, 72-73, 88, 97]. Similar to previous subcategories, results in the I-BAU subgroup were also varied. For example, when comparing e-books with regular preschool activities, four studies [62a, 89, 93-94] found these technological tools to be more favorable in supporting phonological awareness, while another four studies [62, 64-65, 88] did not observe differences between conditions.

3.2.2. RQ2: Which features of educational technology and its implementation are associated with its effectiveness in stimulating preschoolers' early literacy development?

To identify the learning-supportive design characteristics of educational technology and its implementation, we next analyzed the studies following a value-added approach (n = 21). Thirteen of these studies investigated different features of the educational technology [52, 53, 56, 58, 65, 77, 80, 86-87, 89, 93,101, 100]. One study on the feature of realism found that the augmented reality (AR) version of an educational book was more effective in promoting rapid letter naming skills compared to its 2D version, but without support of an effect size [80]. Two studies that addressed metacognitive guidance both reported large effect sizes and found that participants who used the version of the e-book with metacognitive guidance made more progress in phonological awareness than those who used the standard version [89, 93]. Speech manipulation (i.e., slowed down speech rate by 150%) in a computer program with rhyming and synthesis games was found to be less effective but not significantly different in increasing phonological awareness than the version with normal speech rate [87]. Turning to the added value of pictorial cues, two studies analyzed the benefit of using integrated pictorial cues in digital alphabet applications on letter-sound knowledge: one [77] found no significant difference in effectiveness when compared to a version with form-taking pictorial cues, while another [52] reported medium to large effect sizes and found that a version with fading integrated pictorial cues is more effective than another version with non-fading integrated cues or one without pictorial cues at all. Regarding modality, one study reported mixed

findings [53]: both conditions with auditory-only and auditory-and-visual support were more beneficial with large effect sizes for stimulating phonological awareness than conditions without any support, although the conditions with versus without support did not differ in terms of improvement in letter-sound knowledge. Two studies that investigated the feature of adaptivity had contradictory results [58, 101]. Other studies that focused on features of sound categorization [86] and dictionary support and hotspots [65] found no differences in effectiveness. Finally, two studies focused on print referencing features [56, 100]: the latter found that the e-book with a built-in print referencing tool (e.g., highlights letters and words being read by the voice over, print violations of words corrected by an animation) is more beneficial for facilitating print awareness and phonological awareness than a simple e-book and reported large effect sizes, while the former found that simply directing preschoolers' attention to the print did not increase their understanding of print and instead, readability (i.e., pointing out that not all displays are readable) and interactivity features (i.e., requiring child to click on the unreadable items to move on to the next page) promoted their print awareness.

The remaining eight value-added studies investigated features of the implementation of the educational technology [44, 62, 63a-b, 66, 90, 91, 98]. Of these studies, two focused on scaffolding by comparing e-book reading with adult support to that without adult support [63b, 66]. Results of both studies showed significant differences between the two groups in improvement in phonological awareness, in favor of e-book reading with adult support, supported by medium to large effect sizes. In one study that addressed the teacher's instructional focus when implementing educational technology [44], results revealed that emphasizing phonemes was more beneficial for increasing phonological awareness than focusing on vocabulary. Addressing the contribution of grouping structure, two studies showed different results: one [90] did not find differences in e-book reading when done individually or with a partner, while another [91] observed greater gains and large effect sizes in phonological awareness for children who read the e-book with a peer. Moreover, children who took the role of tutor within the pair made most progress. With respect to the number of sessions, two studies again showed different results when comparing the benefit of having five sessions as opposed to only three: one [62] did not observe differences between the two conditions, whereas another [63a] found five sessions to be more favorable (medium effect size) in increasing phonological awareness. Finally, when investigating the potential contribution of an executive functioning support through a stop-and-think procedure implemented using a stuffed animal to which children had to explain their thoughts, one study did not find any differences between the conditions in terms of improvements in phonological awareness and letter-sound knowledge [98].

3.2.3. RQ3: Which child-related characteristics are associated with the effectiveness of educational technology in stimulating preschoolers' early literacy development?

For the third research question, findings from both media comparison and value-added studies were analyzed with respect to child-related characteristics associated with the effectiveness of the educational technology.

Sixteen of the *media comparison* studies examined various child-related characteristics. In terms of specific child characteristics, the studies that addressed gender [59, 78], ethnicity [96], non-verbal cognitive abilities [68], second language learners [74b, 78, 96], and special education status [96] did not find an association with intervention effectiveness. Another specific child characteristic, at-risk status for learning disabilities (LD), was investigated in two studies: the first study [57] did not observe significant differences in the effect of a computer-based training program which uses a bottom-up approach in facilitating the phonological awareness of children at risk of developing LD and those not at risk,

suggesting the effectiveness of the bottom-up computer program for phonological awareness regardless of children's at-risk status for LD. Similarly, the second study [94] did not find differences in phonological awareness gains between the two status groups after intervention but provided evidence for the greatest improvement in another component, print awareness, by the at-risk group that used an e-book. This was in comparison to the improvements made by (a) those without risk of learning disabilities using the same e-book, and (b) those with and without risk of LD who did not use the e-book. In a study that used a computer program based on the syllabic method [72], children with language difficulties had greater gains in phonological awareness, particularly syllabic synthesis, after receiving the intervention compared to their peers without language difficulties. Regarding phonological working memory, one study [78] found phonological working memory scores to be positively associated with improvements in the phonological awareness (particularly, blending sounds) scores of the intervention group after using an online computer-based literacy program. Focusing on children's prior knowledge or pretest scores, seven studies noted different results. Two studies did not find an association of pretest score in letter knowledge with the effectiveness of educational technology [68, 101], while five studies observed a relationship between these two variables [42, 54, 63b, 70, 71]. Of the five studies, four found that children with lower pretest scores on letter-name knowledge and general early literacy benefitted more from the intervention [42, 63b, 70, 71]. For example, one [71] identified greater improvements on phonological awareness of initial low performers who used a phonics-based computer program than the initial low performers who received an alternative non-digital intervention, indicating that educational technology may be particularly beneficial for low-performing children. However, in a different study [54], children with higher pretest scores in rhyming had better outcomes after the intervention: children who had already mastered their rhyme-level skills before the intervention attained greater gains in phonological awareness (particularly, phoneme-level) scores after receiving tablet activities with explicit phonological instruction, compared to those without rhyme-level skill mastery before starting the same intervention.

In terms of child-related environmental factors, SES [81, 101] and home language [101] were considered but found not to be associated with the effectiveness of educational technology.

In terms of intervention-related activities of the child, the amount of time spent to the book [103] and children's rating of the intervention [68] were also found not to be associated with the effectiveness of educational technology. However, regarding the total amount of time children spent in the intervention, two studies showed mixed findings [68, 78]: the first found total intervention time (i.e., time spent using the computer programs) to be associated with phonological awareness growth, while the second did not observe an association between these two variables. With respect to children's collaborative talk [88], i.e., sharing remarks related to the e-book's activation and plot, it was noted that the more children engaged in meaningful, relevant, and unprompted discussion with each other during their joint activity with an e-book, the better was their performance in measures of sub-syllabic phonological awareness. Finally, regarding error rate, one study [99] observed that as children made more errors while playing adaptive computer games, they performed weaker on phonological awareness measures after the intervention.

Turning to the *value-added* studies, five of them examined the potential association of specific child characteristics with the effectiveness of the educational technology. Four studies focused on age [52, 62, 63a, 90]. Of these studies, three did not find an association with effectiveness [52, 63a, 90], while one observed that 4-to-5-year-olds improved their scores in phonological awareness more than 5-to-6-year-olds after either 3 or 5 e-book

intervention sessions [22]. One study examined the association between children's segmentation ability at the phoneme level and the effectiveness of educational technology [52]: in the embedded and without-pictorial-cues conditions, children with good first-sound isolation ability performed better in letter-sound knowledge measures after the intervention; however, in the fading condition, there was no difference between children with good and poor first-sound isolation ability.

Next, turning to child-related environmental factors, SES was also investigated by two value-added studies [62, 65], but this time with mixed findings: the first found no association between children's SES and the effectiveness of an e-book; whereas the second observed significantly greater gains in phonological awareness for children with low SES after either 3 or 5 e-book intervention sessions, compared to (a) mid-SES children who are also in the intervention groups and (b) low- and mid-SES children in the business-as-usual group.

Finally, none of the value-added studies addressed the contribution of intervention-related activities of the child to the effectiveness of the educational technology.

4. Discussion and Conclusion

The aim of the current study was to provide a systematic analysis of the available empirical research on the effectiveness of educational technology for stimulating preschoolers' early literacy development. A systematic search was conducted in four databases which resulted in the analysis of 67 studies. Three research questions, guided the review process and analysis. The first research question centered on the findings of the selected studies following a media comparison approach in investigating the overall effectiveness of educational technology on early literacy outcomes. The second research question considered findings from those studies following a value-added approach by taking into account the features of educational technology and its implementation in improving early literacy outcomes. The third research question focused on child-related characteristics associated with the effectiveness of educational technology in the domain of early literacy. As the conclusions of the review are constrained by the quality of the primary (i.e., included) studies, first a discussion of the limitations of these studies will be provided. Next, the major findings per research question will be discussed. We end the discussion with the limitations of the current systematic review and recommendations for future research.

4.1. Limitations of the primary studies

The findings of the current review are constrained by the limitations of the primary studies. First, the reliability and generalizability of their findings are of concern given the small sample sizes in most studies [108, 109]. In addition to the limited number of participants, most studies concentrated on phonological awareness, on English and Hebrew languages, and on a wide variety of populations, interventions, and study designs, further constraining generalizability of their findings. Second, in nearly all of the included studies, non-cognitive outcomes were not explicitly investigated. Motivation and engagement, for example, are also critical to learning [23, 110] but hardly addressed. Fourth, effect sizes were available for only half of the studies, making it difficult to interpret the actual effectiveness of the (manipulated feature of the) educational technology on preschoolers' early literacy development. Finally, although several features of educational technology and its implementation have been investigated in relation to effectiveness, the number of value-added studies was limited. Additionally, only a small number of studies addressed specific features, further limiting the findings on the key design features.

4.2. Effectiveness of educational technology

The first research question we addressed was "Is educational technology effective in stimulating preschoolers' early literacy development?" by analyzing the studies adhering to the media comparison approach. Overall, almost three-fourth of the media comparison studies reported that the educational technology condition was more effective than the control condition for at least some early literacy outcomes. This suggests that educational technology can be effective for enhancing preschoolers' early literacy development. However, these positive effects were supported by medium to large effect sizes for only half of the studies, and were mainly coming from studies with a passive control group (I-BAU), i.e., a control group that was offered regular instruction in the classroom, but without any specification of the concrete activities these children engaged in during the intervention period. The absence of convincing effect sizes and the absence of concrete information about the instruction offered to the children from the control group pose serious constraints on the interpretation of these positive findings. Together, our findings suggest that educational technology *might* be effective for stimulating young children's early literacy, but strong evidenced-based conclusions cannot be made on the basis of the present review.

Moreover, our review also revealed that in almost one-fourth of the studies, mixed and negative findings were reported, raising additional questions about the potential of educational technology to stimulate young children's early literacy development. These results are consistent with that of a previous review by Cheung and Slavin [23] who found that although educational technology generally produced a positive effect on K-12 students' reading outcomes compared with traditional methods, the impact was small. Other analogous reviews also presented a mixed picture of educational technology's effectiveness in supporting early literacy development [32, 38, 39].

Furthermore, our tentative conclusions related to the potential of educational technology for children's early literacy development mainly relate to one of the four major components of early literacy, namely phonological awareness. Nearly all of the media comparison studies included in our review investigated phonological awareness as the only or one of the early literacy component(s) in children's development. Consequently, the evidence was more elaborate and stronger with respect to the effectiveness of educational technology for phonological awareness than with respect to its effectiveness for enhancing letter-sound knowledge and print awareness (with no media comparison study on RAN). For promoting phonological awareness, digital applications, e-books, and ILS with rhyming, blending, and spelling activities/games tended to be beneficial. Specifically, within the A-ET/EL subcategory, educational technology with code-focused content appeared to be more effective in increasing phonological awareness than those with meaning-focused content. This corroborates the finding of NELP [5] that code-focused interventions had the greatest effect on phonological awareness. Furthermore, it is consistent with the strong agreement on the importance of code-focused instruction in the beginning stages of learning to read [111]. For supporting letter-sound knowledge, digital applications with spelling and letter-related activities/games tend to be favorable. For facilitating print awareness, while e-books and integrated learning systems (ILS) were commonly used in the studies, no clear evidence or trend of effectiveness was found.

Finally, as convincingly argued by Mayer and Clark [28, 29], differences in learning outcomes cannot be simply attributed to the medium, further constraining the findings from media comparison studies included in the present review. Factors such as the design, instructional method, and focus within the medium influence changes in learning [28, 29]. When focusing solely on media comparisons, the importance of instructional design is often forgotten. Aside from asking whether a particular medium works, it is also useful to ask what

makes it work. In this context, value-added research is needed to identify whether certain design features can improve learning and consequently help provide specific recommendations for the design and implementation of learning technologies [112].

4.3. Contribution of educational technology features and child-related characteristics

The second research question we addressed was "Which features of educational technology and its implementation are associated with its effectiveness in stimulating preschoolers' early literacy development?" by analyzing value-added studies. Only one-third of the reviewed studies adhered to a value-added approach and focused on the specific features related to effectiveness. Our systematic search thus revealed a substantially lower number of value-added studies compared to media comparison studies. Moreover, the investigated features were scattered with only one or two value-added studies that focused on a specific feature. And, as was the case for media comparison studies, only for part of the studies, the effectiveness of the intervention was supported by medium to large effect sizes. The low number of value-added studies in general and focusing on concrete educational technology features more specifically as well as the absence of convincing effect sizes, make it difficult to define strong evidence-based guidelines for educational technology design. We can only point to features that might improve the potential of educational technology for preschoolers' early literacy development on the basis of the current review. These features require systematic future studies following a value-added approach, to gain more and deeper insight into their contribution to the effectiveness of the educational technology in early literacy instruction. The first indicative findings of our review and the findings coming from these future studies, can provide foundations for the optimal design of educational technology for preschool children in view of their early literacy development.

Concretely, our review pointed to the potential benefits of augmented reality, metacognitive guidance, and fading pictorial cues for facilitating preschoolers' early literacy development. The positive contribution of realism, particularly AR, may be partially explained by the interaction that happens when engaging with the AR application. Children's motor movements when aligning the device and picture book to activate the animation could help them to efficiently make associations and recognize letters [80]. Another possible explanation for the superior effectiveness of realism is the immersion principle [113]: the higher psychological presence that children experience due to the level of realism offered by AR, facilitates enjoyment which can lead to higher attention and generative processing. Regarding metacognitive guidance embedded in e-books, our results suggest that this feature helps in stimulating the phonological awareness of children at risk for learning disabilities. Guiding learners to plan their response to the task and evaluate their performance afterwards might provide weak readers the support they need to regulate their own learning while reading [88]. Regarding the use of fading pictorial cues, it may be that preschoolers benefitted from stimulus fading as it helped them paying attention to the visual features of the letters [52].

Finally, our third research question focused on the child-related characteristics that might be associated with the effectiveness of educational technology in the domain of early literacy. Similar to the above case concerning features of educational technology, various child characteristics were investigated in media comparison and value-added studies by only a small number of studies, and not supported by convincing effect sizes. Consequently, we can only plea for future studies on the topic, as current findings are limited and do not allow strong evidence-based conclusions. On the basis of our review, preschoolers' prior knowledge is one of the child-related characteristics that requires further investigation. While most studies found prior knowledge to be associated with effectiveness, at least two studies did not find evidence for its contribution towards educational technology effectiveness. Focusing on

the studies that found evidence for the importance of prior knowledge for growth when using educational technology, findings remain unclear whether children with high or low prior knowledge benefit most. This inconsistency may be related to early literacy development in young children. For example, Gilliver and colleagues [54] found that within the group that received explicit phonological awareness instruction and game-like activities via tablets, those participants with rhyme-level skill mastery prior to intervention had greater improvements in phoneme-level scores than those who started the intervention without mastery. This reflects previous findings that children tend to develop sensitivity to larger units in the syllable level earlier than they acquire sensitivity to smaller units at the phoneme level [3, 116], and suggests that the content of educational technology for early readers should focus on rhyming skills before phoneme-level skills [54]. Another possible explanation for the mixed findings related to prior knowledge is the aptitude-treatment interaction theory, which was introduced by Cronbach in 1957 to refer to the concept that some instructions are more or less effective depending on individual abilities and needs [117]. For instance, Korat and Segal-Drori [63] found that participants who initially had a low level of early literacy and received adult-supported e-book reading sessions made greater improvements in phonological awareness than those who also initially had a low level of early literacy but received adult-supported printed book reading sessions, suggesting the benefits of the e-book features (e.g., clicking on a word produces a read-aloud in syllabic and sub-syllabic segmentations) particularly for children with a low literacy level in promoting their phonological awareness. Overall, these findings indicate the importance of accounting for individual characteristics when designing educational technology for learning and that the best intervention involving educational technology may depend on children's individual needs and abilities.

4.4. Limitations of the current review

The current review also has its limitations. One limitation is that it only focused on intervention studies targeting the four early literacy components that directly contribute to word decoding development, and did not take into account children's linguistic comprehension competencies. While these components were selected on the basis of current scientific evidence indicating their central role in early reading development and later reading comprehension competency, preschoolers' linguistic comprehension competencies are also important and might benefit from educational technology use as well. Future reviews can address the potential of educational technology for stimulating preschoolers' linguistic comprehension. Similarly, this review was limited to cognitive learning outcomes related to early literacy. It should be noted that affective and motivational outcomes also need to be taken into account in future investigations, especially as the goal is to include a balance of game features to sustain motivation and instructional features to facilitate learning [28]. Next, given the importance of optimizing preschool instruction for all children, we focused on intervention studies conducted in ecologically-valid school settings. As research interest in the effectiveness of home-based interventions and combined school- and home-based interventions increases as well [e.g., 18], future reviews and meta-analyses might critically compare the effectiveness of technology-enhanced interventions in different (home and school) settings. Furthermore, we focused on early literacy development in alphabetic languages, excluding studies conducted to stimulate early literacy development in non-alphabetic languages. Given the differences between these two types of languages [119], future reviews addressing the effectiveness of educational technology for the stimulation of preschoolers' early literacy development in non-alphabetic languages are needed. Finally, in an effort to increase the quality of this systematic literature review, only published journal articles were included. Unpublished and/or gray literature was excluded, which may lead to

selection bias. We did not systematically check for risk of bias in studies and in the selection of studies, a limitation that might be addressed in future reviews on the topic as well.

4.5. Directions for future research

Notwithstanding its limitations, the present study offers new insights into the effectiveness of educational technology for supporting the early literacy development of preschoolers. Based on our findings, some recommendations for future research can be formulated.

First, there is a need for large-scale studies to evaluate the effect of using educational technology, allow for group comparisons, and increase the generalizability of the findings. Furthermore, in addition to phonological awareness, research attention should also be directed to other early literacy components considered by prior research as strong predictors of reading (e.g., letter-sound knowledge, print awareness, and RAN) as well as other languages.

Second, given the importance of motivation and engagement [23, 28, 110], future research should consider non-cognitive outcomes in investigating the effectiveness of educational technology in stimulating learning. It would be useful to investigate the possible interactions between the cognitive and non-cognitive outcomes, for example, to determine whether higher motivation leads to better learning when children use educational technology and vice-versa. Longitudinal studies would be useful to identify the long-term cognitive and non-cognitive effects of using educational technology. Such longitudinal studies would also allow to determine whether learning gains from educational technology persist beyond possible novelty effects.

Third, although media comparison research helps to evaluate whether particular media are as effective or more effective than conventional media, there is a need to shift research attention towards studies following a value-added approach. The latter type of studies is required to identify design features that can enhance the instructional effectiveness of educational technology and thus deepen our scientific understanding of the topic, also providing building blocks for improving design and educational practices. As outlined above, the inclusion of augmented reality, metacognitive guidance, fading pictorial clues and scaffolding are identified as potential learning-supportive features of educational technology in the domain of early literacy. The systematic analysis of these features in future studies can help to deepen and refine our insights into the most learning-supportive features of educational technology tools in the domain, offering clear guidelines for the design of these tools. In line with the latter, systematic study is needed to determine the conditions under which specific features are most beneficial. This includes the investigation of educational technology's implementation features and children's characteristics. In doing so, the careful design of educational technology may also be used for closing ability gaps between children. Finally, in adding studies to the research base, rigorous and well-designed experimental research is needed. Among many things, this includes ensuring that control conditions are adequate and vary only in one dimension from the intervention condition. Moreover, it is important that a clear and detailed description of the control condition is provided in the report. Future longitudinal and intervention studies following a value-added approach and attending to key characteristics of the educational technology, its implementation and the child it is offered to will help to deepen our insights and optimize current educational practices in the effective use of educational technology for improving young children's early literacy development.

Tables

Table 1. Inclusion and Exclusion Criteria

Criterion	Included	Excluded
Intervention study	The article reports on an intervention study with the following features: (1) use of an intervention by experimental manipulation and standardization of procedures, *and* (2) comparison of the experimental and control conditions, i.e., a study based on true experimental design (randomized controlled trials), quasi-experimental design, or single-subject design (i.e., multiple-baseline or multiple-probe design).	The article is not based on an intervention study, i.e., a study without an intervention involving an experimental manipulation or without a comparison between experimental and control conditions, e.g., review, meta-analysis, correlational study, descriptive study, and case study.
Domain of early literacy	The article focuses on the stimulation of the proximal aspects of reading development in early literacy through the use of educational technology, i.e., print awareness, phonological awareness, rapid automatized naming, and/or letter-sound knowledge.	The article focuses on the distant general aspects of reading development, e.g., oral language and vocabulary; or does not focus on the domain of early literacy, e.g., focuses on the stimulation of development in another content domain with early literacy intervention in the control condition.
Use of educational technology	The article involves: (1) the actual use of digital educational technology *and* (2) with the aim to stimulate and support the learning process of the child in the domain of early literacy during the intervention.	The article does not involve the use of educational technology to stimulate the learning process of the child, e.g., using educational technology in the pre- and post-tests but not as part of the intervention.
In formal organization context	The article focuses on an intervention conducted in a formal organization context outside the family, and is mediated by professionals, e.g., in school or nursery.	The study is not conducted in a formal organization context and/or the intervention is not mediated by professionals, e.g., intervention conducted at home and/or mediated by the parents.
Preschool level	The article focuses on children at the preschool and/or kindergarten level, i.e., intervention is delivered (1) to children before the age of 7 *and* (2) before the start of formal reading instruction.	The article focuses on children at other education levels, e.g., primary school, secondary school, or university level, and/or their teachers.

Table 2. Data analysis: Definitions

Category	Definition
Author (Year)	Name of the author(s) of the report and the year in which the report was published.
Language (Country, Continent)	Language used in the intervention reported in the article, and the country and continent wherein the study was conducted.
Study design	Type of research design used in the study.
Study participants	Descriptions regarding the participants of the study, including the sample size, their age range, and specific characteristics of the sample mentioned in the article. For example, some studies particularly included students from schools serving mainly children from families of low socioeconomic status (SES) or students with disabilities.
Study approach (Subcategory)	Distinction between the two types of research on educational technology as categorized by Mayer [28]: media comparison approach and value-added approach. Following the suggestion of Verbruggen et al. [30], studies adhering to the media comparison approach were further partitioned into subcategories based on the comparison treatment applied to the control group.
Early literacy component (Measure)	Component or subdomain of early literacy that is relevant to the research questions of the current review and measured as an outcome in the primary studies included in the review: PA or phonological awareness, LSK or letter-sound knowledge, RAN or rapid automatized naming, and PRAW or print awareness.
Grouping structure of intervention	Grouping structure used in the intervention, i.e., individual, pair, small-group, or whole-class.
Duration of intervention (Session length)	Total amount of time (weeks and/or number of sessions) of the intervention, including the typical length of each session.
Educational technology and early literacy condition(s)	Materials and/or activities using educational technology and focusing on early literacy that were applied in the intervention condition.
Activities in the control condition/s	Comparison treatment applied in the control condition, i.e., the specification of materials and activities offered to the control group.
Main findings	Findings of the primary studies that are relevant to the current review. Thus, the relevant findings were analyzed per research question focusing on the effectiveness of educational technology (i.e., whether there was a significant difference in outcomes between the conditions and the reported effect size), features of educational technology and its implementation associated with the effectiveness of the intervention, and child-related characteristics associated with the effectiveness of the intervention.

Appendix A - Table 3. Overview of Primary Studies (Description)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Amorim et al. (2020)	Portuguese (Brazil, South America	Quasi-experimental	*N* = 737 4-5 y No other specifications	Media comparison (I-BAU)	PA (PAT-OP by Seabra et al., 2013)	Pair	20 sessions in 10 weeks (45 mins, including 25 mins with the mobile application)
Anthony (2016)	English (US, North America)	True experimental	*N* = 247 5-6 y From low SES	Media comparison (A-ET/NEL)	PA (non-standardized test with tasks created for the study)	Individual	21 weeks (30 or 45 mins)
Bauserman et al. (2005)	English (US, North America)	Quasi-experimental	*N* = 88 5-7 y From low SES	Media comparison (A-ET/NEL)	PRAW (CAP test by Clay, 1979); PA (PAT by Cassady et al., 2002)	Individual	8 weeks (30 mins)
Brabham et al. (2006)	English (US, North America)	Quasi-experimental	*N* = 152 5-7 y No other specifications	1: Value-added 2-3: Media comparison (A-NET/EL)	PA (TPI by Murray et al., 2000)	Varied (individual, pair, and small-group)	6 sessions in 4 weeks (10-15 mins)
Campbell and Mechling (2009)	English (US, North America)	Single-subject (Multiple-probe)	*N* = 3 5-6 y With learning disabilities	Media comparison (I-BAU)	LSK (task created for the study)	Varied (individual and small-group)	24 sessions in 5-6 weeks (10-20 mins)
Carson (2020)	English, (Australia, Oceania)	Quasi-experimental	*N* = 24 4-5 y At-risk for reading difficulties due to developmental language disorder	Media comparison (I-BAU)	LSK (tasks from online PA probes); PA (subtests from PIPA by Dodd et al., 2000, and tasks from online PA probes)	Individual	16 sessions in 8 weeks (20-25 mins)
Cassady and Smith (2003)	English (US, North America)	Quasi-experimental	*N* = 88 5-7 y No other specifications	Media comparison (A-NET/EL)	PRAW (CAP test); PA (PAT by Cassady et al., 2002)	Individual	1 school year of daily sessions (20 mins)
Chai et al. (2015)	English (US, North America)	Single-subject (Multiple-probe)	*N* = 2 5-6 y With developmental delays	Media comparison (I-BAU)	PA (in-game scores)	Individual	61-68 sessions in 6-7 weeks (10 mins)
Chera and Wood (2003)	English (UK, Europe)	Quasi-experimental	*N* = 30 3-6 y No other specifications	Media comparison (I-BAU)	PA (subtests from PA Training by Wilson, 1993)	Individual	10 sessions in 4 weeks (10 mins)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Comaskey et al. (2009)	English (Canada, North America)	True experimental	*N* = 53 5-6 y From low SES; English language learners (ELLs)	Media comparison (A-ET/EL)	PA (tasks created for the study)	Small-group	40 sessions in 13-16 weeks (10-15 mins)
Davidson et al. (2009)	English (US, North America)	Quasi-experimental	*N* = 254 4-5 y From low SES	Media comparison (A-NET/EL)	PA (ISF subtest from DIBELS 2002, rhyming subtest from WJ III, and blending subtest from CTOPP)	Small-group (4) in rotating center	1 school year (Varied)
de Graaff et al. (2007)	Dutch (Netherlands, Europe)	True experimental	*N* = 39 5-7 y No other specifications	1-2: Value-added	LSK (receptive and productive tasks created for the study)	Individual	6 sessions in 2 weeks (25 minutes)
Elimelech and Aram (2020)	Hebrew (Israel, Asia)	True experimental	*N* = 129 4-6 y From low SES	1-2: Value-added 3: Media comparison (A-ET/EL)	LSK (task in Hebrew created for the study); PA (test created by Levin & Aram, 2013)	Individual	8 sessions in 4 weeks (20 mins)
Gilliver et al. (2016)	English, (Australia, Oceania)	Quasi-experimental	*N* = 30 3-5 y With physical disabilities (deaf and hard-of-hearing)	Media comparison (A-ET/EL)	PA (test created for the study with items based on word set used in the intervention)	Individual	6 sessions in 6 weeks (20-30 mins)
Goffredo et al. (2016)	Italian (Italy, Europe)	True experimental	*N* = 16 3-6 y Typically-developing	Media comparison (I-BAU)	PA (CMF by Marotta et al., 2008)	Individual	5 sessions in 5 weeks (20 mins)
Gong and Levy (2009)	English (Canada, North America)	True experimental	*N* = 96 4-5 y Typically-developing	1-3: Value-added	PRAW (print discrimination task by Levy et al., 2006)	Individual	6 sessions in 4 weeks (10-15 mins)
Helland et al. (2011)	Norwegian (Norway, Europe)	Quasi-experimental	*N* = 49 5 y At-risk for dyslexia; Typically-developing children	Media comparison (A-ET/EL)	PA (rhyme, same initial phoneme, and phoneme deletion subtests from Ringerik Material by Lyster et al., 2002)	Individual	40 sessions in 8 weeks (20 mins)
Hooshyar et al. (2018)	English (South Korea, Asia)	True experimental	*N* = 102 4-6 y No other specifications	Value-added	LSK (in-game scores); PA (in-game scores)	Individual	Unclear

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Ihmeideh (2014)	Arabic (Jordan, Asia)	Quasi-experimental	*N* = 92 4-5 y From low and middle SES; Typically-developing	Media comparison (A-NET/EL)	PRAW (CAP test by Clay, 1979, adapted to Hebrew); LSK (task created for the study); PA (items created for the study)	Individual	40 sessions in 8 weeks (15 mins)
Kartal et al. (2016)	Turkish (Turkey, Asia)	Quasi-experimental	*N* = 53 4-6 y No other specifications	1-2: Media comparison (A-NET/EL; I-BAU)	PA (PASS-T)	Individual	8-12 sessions in 4-6 weeks (17 mins)
Kartal and Terziyan (2016)	Turkish (Turkey, Asia)	True experimental	*N* = 20 4-6 y From low SES	Media comparison (A-ET/NEL)	LSK (task created for the study); PA (PASS-T)	Individual	27 sessions in 9 weeks (12 mins)
Korat and Blau (2010)	Hebrew (Israel, Asia)	True experimental	*N* = 247 4-6 y From low and middle SES	1: Value-added 2: Media comparison (I-BAU)	PA (sub-syllabic segmentation task created for the study with target words from the storybook)	Small-group (3; without adult support)	3 or 5 sessions (20-25 mins)
Korat and Segal-Drori (2016) (Study 1)	Hebrew (Israel, Asia)	True experimental	*N* = 214 4-6 y From low SES	1: Value-added 2: Media comparison (I-BAU)	PA (test created for the study)	Individual	3 or 5 sessions (20-25 mins)
Korat and Segal-Drori (2016) (Study 3)	Hebrew (Israel, Asia)	True experimental	*N* = 128 5-6 y From low SES	1: Value-added 2-3: Media comparison (A-NET/EL; I-BAU)	PRAW (CAP test by Clay, 1979, adapted to Hebrew); LSK (task created for the study); PA (test created for the study)	Individual	4 sessions (15-20 mins)
Korat and Shamir (2007)	Hebrew (Israel, Asia)	True experimental	*N* = 128 5-6 y From low and middle SES	1-2: Media comparison (A-NET/EL; I-BAU)	PA (sub-syllabic segmentation task created for the study)	Individual	3 sessions (20-35 mins)
Korat and Shamir (2008)	Hebrew (Israel, Asia)	True experimental	*N* = 149 5-6 y From low and middle SES	1-2: Value-added 3: Media comparison (I-BAU)	PA (sub-syllabic segmentation task created for the study)	Individual	3 sessions (20-35 mins)
Korat et al. (2011)	Hebrew (Israel, Asia)	True experimental	*N* = 96 5-6 y From low SES	1: Value-added 2: Media comparison (I-BAU)	PA (opening and closing phoneme tasks by Aviram, 2004, and syllabic and sub-syllabic segmentation tasks created for the study)	Pair	4 sessions (15-20 mins)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Kozminsky and Asher-Sadon (2013)	Hebrew (Israel, Asia)	Quasi-experimental	*N* = 50 5-7 y Typically-developing	Media comparison (A-NET/EL)	PRAW; PA (measures adapted from existing tests by Blum, 2001; Drori, 1998; and Tuval and Zeiler, 1995)	Individual	5 sessions (10-31 mins)
Lonigan et al. (2003).	English (US, North America)	True experimental	*N* = 41 3-5 y At-risk for reading difficulties	Media comparison (A-NET/EL)	PA (rhyme oddity, rhyme matching, word blending, syllable and phoneme blending, word elision, syllable and phoneme elision tasks created for the study)	Individual	32-40 sessions in 8 weeks (15-20 mins)
Macaruso and Rodman (2011a)	English (US, North America)	Quasi-experimental	*N* = 66 3-5 y English language learners (ELLs)	Media comparison (A-ET/NEL)	PRAW; PA (print awareness, sound matching, and rhyming subtests from GRADE Level K by Williams, 2001)	Individual	55 sessions in 32 weeks (15-20 mins)
Macaruso and Rodman (2011b)	English (US, North America)	Quasi-experimental	*N* = 38 4-5 y Typically-developing	Media comparison (I-BAU)	PA (sound matching and rhyming subtests from GRADE Level K by Williams, 2001)	Individual	16 weeks (10-15 mins)
Macaruso and Rodman (2011b) (Study 2)	English (US, North America)	Quasi-experimental	*N* = 66 5-6 y No other specifications	Media comparison (I-BAU)	PRAW; PA (print awareness, sound matching, and rhyming subtests from GRADE Level K by Williams, 2001)	Individual	7 months (15-20 mins)
Macaruso and Walker (2008)	English (US, North America)	Quasi-experimental	*N* = 71 5-6 y No other specifications	Media comparison (A-NET/EL)	PA (ISF and PSF subtests from DIBELS, and oral language concepts subtest from GMRT 2000)	Individual	48 sessions in 24 weeks (15-20 mins)
Majorano et al. (2022)	Italian (Italy, Europe)	True experimental	*N* = 63 5 y No other specifications	Media comparison (I-BAU)	LSK (vowel recognition task); PA (CMF by Marotta et al., 2008)	Individual	36 sessions in 12 weeks (15 mins)
Maureen et al. (2022)	Indonesian (Indonesia, Asia)	Quasi-experimental	*N* = 59 4-5 y No other specifications	1-2: Media Comparison (A-NET/EL; I-BAU)	PRAW; PA (Get Ready to Read! By Whitehurst, 2001)	Whole-class	6 sessions in 6 weeks (90 mins)
Metsala and Kalindi (2022) (Study 1)	English (Canada, North America)	Quasi-experimental	*N* = 55 4-6 y From mid SES	Media comparison (I-BAU)	PA (blending and elision subtests from CTOPP)	Individual	3 months (Unclear)
Metsala and Kalindi (2022) (Study 2)	English (Canada, North America)	Quasi-experimental	*N* = 88 4-6 y From mid SES	Media comparison (I-BAU)	PA (blending and elision subtests from CTOPP)	Individual	6 months (Unclear)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Mioduser et al. (2000)	Hebrew (Israel, Asia)	Quasi-experimental	*N* = 46 5-6 y At-risk for reading disabilities	1-2: Media comparison (A-NET/EL; I-BAU)	PA (PAT by Lapidot et al., 1995)	Individual	1 school year (Unclear)
Neumann (2018)	English, (Australia, Oceania)	True experimental	*N* = 48 5-6 y With learning disabilities; At-risk for learning and reading disabilities	Media comparison (I-BAU)	PRAW (CAP test by Clay, 2005); LSK (test created for the study)	Individual	9 sessions in 9 weeks (30 mins)
Nicholas et al. (2016)	English, (Australia, Oceania)	Quasi-experimental	*N* = 48 5-6 y From low SES	1: Value-added 2: Media comparison (A-NET/EL)	LSK (test created for the study)	Varied (individual, pair, and small-group)	10 sessions in 10 weeks (20 mins)
O'Callaghan et al. (2016)	English (UK, Europe)	True experimental	*N* = 98 4-6 y Below-average students	Media comparison (I-BAU)	PA (blending and phoneme segmentation subtests from PhAB-2)	Individual	40 sessions in 8 weeks (20-30 mins)
Oliva-Maza et al. (2021)	Spanish (Spain, Europe)	Quasi-experimental	*N* = 4 No other specifications	I-BAU	PA (rubric created by the researchers)	Varied (individual and small-group)	2 weeks of daily sessions (Unclear)
Pan et al. (2021)	English (US, North America)	Quasi-experimental	*N* = 76 3-6 y No other specifications	Value-added	RAN (task created for the study)	Individual	6 weeks (10-30 mins)
Penuel et al. (2012)	English (US, North America)	Quasi-experimental	*N* = 436 3-4 y From low SES	Media comparison (A-ET/NEL)	LSK; PA (letter sounds and beginning sound subtests from PALS-PreK)	Whole-class	10 weeks = 25 hours (Varied)
Putman (2017)	English (US, North America)	Quasi-experimental	*N* = 72 5-7 y No other specifications	Media comparison (I-BAU)	PRAW; LSK; PA (CAP, letter sounds, and hearing/recording sounds subtest from OSELA 2002)	Individual	20-24 weeks (Unclear)
Reitsma and Wesseling (1998)	Dutch (Netherlands, Europe)	Quasi-experimental	*N* = 98 4-5 y No other specifications	Media comparison (A-ET/EL)	PA (blending and phoneme segmentation tasks created for the study)	Individual	24 sessions in 12 weeks (10 mins)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
K. M. Ross and Joseph (2021)	English (US, North America)	Single-subject (Multiple-probe)	*N* = 5 5-6 y English language learners (ELLs)	Media comparison (I-BAU)	LSK (task created for the study with trained and untrained words)	Individual	16 weeks (15 mins)
Sa et al. (2022)	Portuguese (Portugal, Europe)	True experimental	*N* = 49 Typically-developing	Media comparison (I-BAU)	PA (subtests from the Phonological Awareness Tasks by Afonso, 2015 and OLA by Sim-Sim, 2001)	Individual	5 sessions in 5 weeks (60 mins)
Samur (2019)	Turkish (Turkey, Asia)	Quasi-experimental	*N* = 87 4-5 y No other specifications	1: Value-added 2: Media comparison (I-BAU)	LSK (test created for the study)	Individual	12 sessions in 12 weeks (10 mins)
Segers and Verhoeven (2004)	Dutch (Netherlands, Europe)	Quasi-experimental	*N* = 36 4-6 y With specific language impairment	1: Value-added 2: Media comparison (A-ET/EL)	PA (tasks from existing tests)	Individual	5 weeks (15 mins)
A. Shamir (2009)	Hebrew (Israel, Asia)	True experimental	*N* = 96 5-6 y From low SES	Media comparison (I-BAU)	PA (syllabic and sub-syllabic segmentation tasks in Hebrew by Shamir et al., 2008)	Pair	3 sessions (35 mins)
A. Shamir (2017)	Hebrew (Israel, Asia)	True experimental	*N* = 78 4-7 y At-risk for learning disabilities	1: Value-added 2: Media comparison (I-BAU)	PA (rhyming measure created for the study)	Individual	6 sessions (20 mins)
A. Shamir and Korat (2007)	Hebrew (Israel, Asia)	True experimental	*N* = 72 5-6 y From low SES; Typically-developing	Value-added	PA (sub-syllabic segmentation task created for the study)	Varied (individual or pair)	3 sessions (30 mins)
A. Shamir et al. (2008)	Hebrew (Israel, Asia)	True experimental	*N* = 110 5-6 y From low SES; Typically-developing	1: Value-added 2: Media comparison (I-BAU)	PA (syllabic and sub-syllabic segmentation tasks created for the study, and initial and final phoneme tasks by Aram & Levin, 2001)	Pair: Tutor/tutee	2-3 sessions (30 mins)
A. Shamir et al. (2012)	Hebrew (Israel, Asia)	Quasi-experimental	*N* = 110 5-7 y At-risk for learning disabilities	1-2: Media comparison (A-NET/EL; I-BAU)	PRAW (CAP test adapted to Hebrew); PA (sub-syllabic awareness task created for the study)	Varied (Individual for e-book; small groups for printed book)	6 sessions (20-35 mins)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
A. Shamir and Lifshitz (2013)	Hebrew (Israel, Asia)	True experimental	*N* = 77 4-7 y At-risk for learning disabilities	1: Value-added 2: Media comparison (I-BAU)	PA (rhyming measure created for the study)	Individual	5 or 6 sessions (20 mins)
A. Shamir and Shlafer (2011)	Hebrew (Israel, Asia)	True experimental	*N* = 136 5-7 y At-risk for learning disabilities	Media comparison (I-BAU)	PRAW (CAP test adapted to Hebrew by Shatil, 2001); PA (sub-syllabic awareness measure created for the study)	Individual	6 sessions (20-35 mins)
H. Shamir et al. (2017)	English (US, North America)	Quasi-experimental	*N* = 516 5-7 y No other specifications	Media comparison (I-BAU)	PRAW; PA (concept of word and phonemic awareness subtests from STAR EL Assessments, and PSF subtest from DIBELS)	Individual	1 school year of daily sessions (15 mins)
H. Shamir et al. (2018)	English (US, North America)	Quasi-experimental	*N* = 1696 5-7 y No other specifications	Media comparison (I-BAU)	LSK; PA (subtests from TPRI)	Individual	1 school year of daily sessions (15 mins)
Tracey and Young (2007)	English (US, North America)	Quasi-experimental	*N* = 265 5-7 y From low SES; At-risk for early literacy delays	Media comparison (I-BAU)	PA (LAC Test)	Individual	32 weeks of daily sessions (15 mins)
van de Sande et al. (2016)	Dutch (Netherlands, Europe)	True experimental	*N* = 101 4-7 y No other specifications	1: Value-added 2: Media comparison (A-ET/EL)	LSK; PA (tasks from existing tests)	Individual	10 sessions in 5 weeks (20 mins)
Van der Kooy-Hofland et al. (2012)	Dutch (Netherlands, Europe)	True experimental	*N* = 110 5-6 y At-risk for or with early literacy delays	Media comparison (A-ET/EL)	LSK; PA (measures created for the study)	Individual	15 sessions in 15 weeks (10-15 mins)
Van Dijken (2023)	Dutch (Netherlands, Europe)	Quasi-experimental	*N* = 80 4-6 y Typically-developing	Value-added	PRAW (Concepts of Print Test); PA (phoneme combination and syllables clapping subtests from CELF-4-NL by Kort et al., 2008)	Whole-class	6 sessions in 2 weeks (Unclear)
Vanbecelaere et al. (2020)	Dutch (Belgium, Europe)	Quasi-experimental	*N* = 191 5-6 y No other specifications	1: Value-added 2: Media comparison (A-NET/EL)	LSK (Letterkennistoets 1 and 2 by Aarnoutse et al., 2010); PA (standardized test by Aarnoutse et al., 2010)	Individual	5 sessions in 5 weeks (30 mins)

Author (Year)	Language (Country, Continent)	Study design	Study participants	Study approach (Subcategory[a])	Early literacy component (Measure)	Grouping structure of intervention	Duration of intervention (Session length)
Watkins and Dehaene (2023)	French (France, Europe)	Quasi-experimental	*N* = 783 3-5 y No other specifications	1-2: Media comparison (A-ET/NEL; I-BAU)	LSK (matching task); PA (same initial phoneme and same ending phoneme tasks)	Small-group	Varied (20-30 mins)
Willoughby et al. (2015)	English (Canada, North America)	Quasi-experimental	*N* = 94 3-4 y No other specifications	1-2: Media comparison (A-NET/EL)	LSK (task created for the study); PA (initial sound-same subtest from TOPA-K)	Varied (individual and small-group)	16 sessions in 8 weeks (20 mins)
Wood et al. (2013)	English (US, North America)	Single-subject (Multiple-probe)	*N* = 4 5-7 y At-risk for reading failure	Media comparison (I-BAU)	PA (PSF subtest from DIBELS)	Pair: Tutor/tutee	Varied (7 mins)

Note. CAP = Concepts about Print; CELF-4-NL = Clinical Evaluation of Language Fundamentals 4 Dutch version; CMF = Valutazione delle Competenze Metafonologiche; CTOPP = Comprehensive Test of Phonological Processing; DIBELS = Dynamic Indicators of Basic Early Literacy Skills; GMRT = Gates-MacGinitie Reading Test; GRADE = Group Reading Assessment and Diagnostic Evaluation; ISF = Initial Sound Fluency; LAC = Lindamood Auditory Conceptualization; LSK = letter-sound knowledge; OLA = Oral Language Assessment; OSELA = Observation Survey of Early Literacy Achievement; PA = phonological awareness; PALS-PreK = Phonological Awareness Literacy Screening for pre-Kindergarten; PASS-T = Phonological Awareness Skills Screening Test for Turkish; PAT = Phonological Awareness Test; PAT-OP = Phonological Awareness Test by Oral Production; PhAB = Phonological Awareness Battery 2nd Edition; PRAW = print awareness; RAN = rapid automatized naming; STAR = Standardized Test for the Assessment of Reading; TOPA-K = Test of Phonological Awareness – kindergarten version; TPI = Test of Phoneme Identities; TPRI = Texas Primary Reading Inventory; WJ III = Woodcock-Johnson Tests of Achievement III.

[a] A-ET/EL = active control group with educational technology/early literacy treatment; A-ET/NEL = active control group with educational technology/non-early literacy treatment; A-NET/EL = active control group with non-technology/early literacy treatment; A-NET/NEL = active control group with non-technology/non-early literacy treatment; I-BAU = inactive control group with unclear description or business as usual.

Appendix B - Table 4. Overview of Primary Studies (Findings)

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Amorim et al. (2020)	Media comparison (I-BAU)	Game-enhanced instructional program using "Escribo Play" tablet application	No intervention	No (0)	NA	NA	NA
Anthony (2016)	Media comparison (A-ET/NEL)	Computer games for PA from "Earobics Step 1" software	“Building Blocks” math software	No (0)	NA	NA	Pretest scores (- with rhyme skills)
Bauserman et al. (2005)	Media comparison (A-ET/NEL)	PLATO ILS "Beginning Reading for the Real World, Level A" as part of computer center time	Varied literacy and math programs as part of computer center time	Yes (+)	Medium	NA	NA
Brabham et al. (2006)	1: Value-added 2-3: Media comparison (A-NET/EL)	Independent practice center using computer e-book focusing on phonemes 1: Independent practice center using computer e-book focusing on vocabulary	2: Independent practice center using printed books and audiotape read-aloud focusing on phonemes 3: Independent practice center using printed books and audiotape read-aloud focusing on vocabulary	2-3: Yes (-)	Small	1: Instructional focus [Vocabulary vs. Phoneme (+ for phoneme-focus)]	NA
Campbell and Mechling (2009)	Media comparison (I-BAU)	Small-group CAI using SMART Board technology (large interactive touch screen)	No intervention	Yes (+)	NA	NA	NA
Carson (2020)	Media comparison (I-BAU)	Reading Doctor iPad applications instead of usual small group instruction	No intervention	Yes (+)	Large	NA	NA
Cassady and Smith (2003)	Media comparison (A-NET/EL)	ILS Waterford "Early Reading Program"	Professional development on reading promotion for teachers	Yes (+)	Medium for PRAW Large for PA	NA	NA
Chai et al. (2015)	Media comparison (I-BAU)	Researcher-developed iPad application "Touch Sound"	No intervention	Yes (+)	NA	NA	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Chera and Wood (2003)	Media comparison (I-BAU)	Computer e-books with activity pages	No intervention	Yes (+)	NA	NA	NA
Comaskey et al. (2009)	Media comparison (A-ET/EL)	Synthetic phonics activities from web-based computer program "ABRACADABRA" as part of reading center Analytic phonics activities from web-based computer program "ABRACADABRA" as part of reading center	NA	Mixed: in favor of synthetic group for PA blending, and common-coda; analytic group for PA common-rime	NA	NA	NA
Davidson et al. (2009)	Media comparison (A-NET/EL)	"Ready, Set, Learn" technology-enhanced literacy program with paper-based technology	Non-technology literacy program	No (0)	Small	NA	NA
de Graaff et al. (2007)	1-2: Value-added	Computer training program using integrated-picture mnemonics with fading procedure 1: Embedded without fading condition 2: Without picture condition	NA	NA	NA	1: Fading condition [Embedded vs. Fading (+ in favor of fading)] 2: Pictorial cue [Without vs. With (0)]	Age (0) Segmentation ability (0 with fading condition)

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Elimelech and Aram (2020)	1-2: Value-added 3: Media comparison (A-ET/EL)	Researcher-designed digital spelling game on laptop with auditory support 1: Digital spelling game with auditory and visual support 2: Digital spelling game without support 3: Narrative e-book watching	NA	3: Yes (in favor of digital spelling game)	Medium to large	1-2: Modality [No Support vs. Auditory Support vs. Auditory+Visual Support (0 for LSK; + in favor of groups with support for PA, no difference between groups with support)]	NA
Gilliver et al. (2016)	Media comparison (A-ET/EL)	Researcher-developed tablet teaching activities with explicit PA instruction Researcher-developed tablet teaching activities with vocabulary-focused instruction	NA	Yes (in favor of explicit-PA group)	NA	NA	Pretest scores (+ with phoneme-level skills)
Goffredo et al. (2016)	Media comparison (I-BAU)	Researcher-developed computer platform "En Plein" with interactive motion-based activities	No intervention	Yes (+)	NA	NA	NA
Gong and Levy (2009)	1-3: Value-added	Computer e-book story sessions - Story Control condition 1: Bouncing ball condition 2: Violation condition 3: Action condition	NA	NA	NA	1-3: Attention and Readability [Story Control (0), Bouncing Ball (0), Violation (+), Action (+)] Interactivity [Violation vs. Action (+ in favor of Action)]	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Helland et al. (2011)	Media comparison (A-ET/EL)	Computer-based training program "Fast ForWord" with BU approach Computer-based training program "Omega-Is" with TD approach	NA	Yes (in favor of BU condition)	Large	NA	At-risk status for dyslexia (0 with BU condition)
Hooshyar et al. (2018)	Value-added	Language learning tablet game - adaptive condition Language learning tablet game - non-adaptive condition	NA	NA	NA	Adaptivity (+)	NA
Ihmeideh (2014)	Media comparison (A-NET/EL)	E-book reading with book-related activities	Printed book reading with book-related activities	Yes (+)	NA	NA	Gender (0)
Kartal et al. (2016)	1-2: Media comparison (A-NET/EL; I-BAU)	Researcher-developed computer software with 14 modules of exercises embedded in story	1: Non-technology game-like in-class training 2: No intervention	1-2: Yes (+), but none in follow-up	Medium	NA	NA
Kartal and Terziyan (2016)	Media comparison (A-ET/NEL)	Computer software "JerenAli" with exercises embedded in stories	Math software	Mixed (+ for LSK and PA phoneme segmentation; 0 for other PA subtests)	NA	NA	NA
Korat and Blau (2010)	1: Value-added 2: Media comparison (I-BAU)	Researcher-developed "considerate" e-book with different modes - Three-session condition 1: Five-session condition	2: No intervention	2: No (0)	NA	1: Number of sessions [3 vs. 5 sessions (0 for PA, but + for word reading)]	NA
Korat and Segal-Drori (2016) (Study 1)	1: Value-added 2: Media comparison (I-BAU)	Researcher-developed "considerate" e-book with different modes - Three-session condition 1: Five-session condition	2: No intervention	2: Yes (+)	Medium	1: Number of sessions [3 vs. 5 sessions (+ in favor of 5 sessions)]	Age (0)

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Korat and Segal-Drori (2016) (Study 3)	1: Value-added 2-3: Media comparison (A-NET/EL; I-BAU)	Researcher-developed "considerate" e-book reading with adult support 1: Without adult support condition	2: Printed book reading with adult support 3: No intervention	2-3: Mixed (+ for PA, but 0 for PRAW and LSK)	Medium	1: Scaffolding [Mixed (+ for PA, but 0 for PRAW and LSK)]	NA
Korat and Shamir (2007)	1-2: Media comparison (A-NET/EL; I-BAU)	Researcher-developed "considerate" e-book reading with different modes	1: Printed book reading with limited adult support 2: No intervention	1-2: No (0)	NA	NA	SES (0)
Korat and Shamir (2008)	1-2: Value-added 3: Media comparison (I-BAU)	Researcher-developed "considerate" e-book reading - Story only condition 1: Dictionary mode condition 2: Play mode condition	3: No intervention	3: No (0 for PA, but + for word meaning and word recognition)	NA	1: Dictionary (0 for PA, + for word meaning and recognition) 2: Hotspot [PA vs. Story Comprehension (0)]	SES (-)
Korat et al. (2011)	1: Value-added 2: Media comparison (I-BAU)	Researcher-developed "considerate" e-book reading with adult support 1: Without adult support condition	2: No intervention	2: Mixed (+ for PA opening and closing phoneme, 0 for PA sub-syllabic segmentation)	Medium to large	1: Scaffolding (+)	NA
Kozminsky and Asher-Sadon (2013)	Media comparison (A-NET/EL)	Researcher-developed e-book reading with two story sessions and three sessions for digital literacy activities	Printed book reading session with two story sessions and three sessions for literacy activities with experimenter	Mixed (0 for PA, - for PRA)	Medium	NA	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Lonigan et al. (2003).	Media comparison (A-NET/EL)	CAI programs "Daisy's Quest" and "Daisy's Castle"	Non-technology Head Start program	Mixed (+ for Rhyme Matching, Word Elision, Syllable and Phoneme Elision; 0 for other PA subtests)	Large	NA	Pretest scores [Vocabulary (0); Letter knowledge (0)] Amount of time spent on the intervention (+) Non-verbal cognitive abilities (0) Rating of CAI program (0)
Macaruso and Rodman (2011a)	Media comparison (A-ET/NEL)	CAI programs "Lexia Early Reading" and "Primary Reading"	Unstructured computer use with varied literacy and math activities	Mixed (+ for PA; 0 for PRA)	Medium	NA	Pretest scores (-)
Macaruso and Rodman (2011b)	Media comparison (I-BAU)	CAI program "Lexia Early Reading"	No intervention	Yes (+)	Large	NA	NA
Macaruso and Rodman (2011b) (Study 2)	Media comparison (I-BAU)	CAI programs "Lexia Early Reading" and "Lexia Primary Reading"	No intervention	No (0)	NA	NA	NA
Macaruso and Walker (2008)	Media comparison (A-NET/EL)	CAI program "Lexia Early Reading"	Non-technology language arts activities	Yes (+)	NA	NA	Pretest scores (-)
Majorano et al. (2022)	Media comparison (I-BAU)	Computer-based program “Simpo-syl” based on the syllabic method	No intervention	No (0 for LSK and PA, but + for word reading)	Large	NA	Language difficulties (+ for syllabic synthesis)
Maureen et al. (2022)	1-2: Media comparison (A-NET/EL; I-BAU)	Digital storytelling activities using projection device	1: Oral storytelling 2: No intervention	1-2: No (0)	Large	NA	NA
Metsala and Kalindi (2022) (Study 1)	Media comparison (I-BAU)	Computer reading program “Ooka Island” which has game-like activities for decoding- and meaning-related skills	No intervention (Balanced literacy approach)	Mixed (+ for PA blending, 0 for PA segmentation)	Large	NA	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Metsala and Kalindi (2022) (Study 2)	Media comparison (I-BAU)	Computer reading program “Ooka Island” which has game-like activities for decoding- and meaning-related skills	No intervention (Balanced literacy approach)	Mixed (+ for PA blending, 0 for PA segmentation)	Medium	NA	English language learner status (0)
Mioduser et al. (2000)	1-2: Media comparison (A-NET/EL; I-BAU)	Reading program "I have a secret - I can read" using touchscreen software	1: Same reading program with printed materials only 2: No intervention	Yes (+)	NA	NA	NA
Neumann (2018)	Media comparison (I-BAU)	iPad literacy program with selected apps "Endless Alphabet", "Letter School", and "Draw Buddy"	No intervention	Mixed (+ for LSK, 0 for PRAW)	Medium	NA	NA
Nicholas et al. (2016)	1: Value-added 2: Media comparison (A-NET/EL)	Researcher-developed tablet application "A to Z Safari" with guided reading sessions - Integrated picture cues condition 1: Form-taking picture cues condition	2: Non-technology teacher-led activities in guided reading session	2: Yes (-)	NA	1: Pictorial cues [Form-taking vs. Integrated (0)]	NA
O'Callaghan et al. (2016)	Media comparison (I-BAU)	Online CAI program Lexia Reading Core5 without adult-mediated support	No intervention	Mixed (+ for PA blending; 0 for PA phoneme segmentation)	Small to medium	NA	Gender (0) Phonological working memory (+) English language learner status (0) Amount of time spent on the intervention (0)
Oliva-Maza et al. (2021)	Media comparison (I-BAU)	Multimedia adventure game with tangible technology	No intervention	Yes (+)	NA	NA	NA
Pan et al. (2021)	Value-added	Researcher-developed book set as part of learning center - AR condition 2D condition		NA	NA	Realism [2D vs. AR (+ in favor of AR)]	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Penuel et al. (2012)	Media comparison (A-ET/NEL)	Media-rich curriculum supplement "PBS Kids Raising Readers Curriculum Supplement"	Science media supplement	Mixed (+ for LSK; 0 for PA)	Medium	NA	SES (0)
Putman (2017)	Media comparison (I-BAU)	ILS Istation "Early Reading"	No intervention	Mixed: (+ for PA and LSK; 0 for PRAW)	NA	NA	NA
Reitsma and Wesseling (1998)	Media comparison (A-ET/EL)	CAI training program with exercises focusing on blending Same computer program with exercises for vocabulary	NA	Yes (in favor of blending exercises)	Large	NA	NA
K. M. Ross and Joseph (2021)	Media comparison (I-BAU)	iPad application "Build a Word - Easy Spelling with Phonics"	No intervention	Yes (+)	Medium	NA	NA
Sa et al. (2022)	Media comparison (I-BAU)	“Phonological Awareness Digital Program”	No intervention	Yes (+)	NA	NA	NA
Samur (2019)	1: Value-added 2: Media comparison (I-BAU)	Researcher-developed mobile game "Kes Sesi" - without categorization condition 1: With predefined sound categorization condition	2: No intervention	2: Yes (+)	Medium	1: Sound categorization (0)	NA
Segers and Verhoeven (2004)	1: Value-added 2: Media comparison (A-ET/EL)	Researcher-developed computer program with rhyming and synthesis games - Normal speech condition 1: Slowed down speech condition 2: Computer vocabulary games condition	NA	2: Yes (in favor of rhyming and synthesis games)	Large	1: Speech manipulation [Slowed vs. Normal (0)]	NA
A. Shamir (2009)	Media comparison (I-BAU)	Researcher-developed e-book with different modes and pair activity	No intervention	No (0 for PA, but + for total early literacy score with PA and word meaning)	NA	NA	Collaborative talk (+)

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
A. Shamir (2017)	1: Value-added 2: Media comparison (I-BAU)	Researcher-developed e-book with different modes - Metacognitive guidance condition 1: Without metacognitive guidance condition	2: No intervention	2: Yes (+)	Medium	1: Metacognitive guidance (+)	NA
A. Shamir and Korat (2007)	Value-added	Researcher-developed e-book with different modes and activity - Pair condition Value-added (Individual condition)	NA	NA	NA	Grouping structure [Individual vs. Pair (0)]	Gender (0)
A. Shamir et al. (2008)	1: Value-added 2: Media comparison (I-BAU)	Commercially available e-book with different modes and activity sessions - Pair condition 1: Individual condition	2: No intervention	Mixed (+ for PA sub-syllabic, 0 for other PA subtests)	Large	1: Grouping structure [Individual vs. Pair (+, even greater for tutor)]	NA
A. Shamir et al. (2012)	1-2: Media comparison (A-NET/EL; I-BAU)	Researcher-developed e-book with different modes and structured activities	1: Small-group adult-led reading of printed book) 2: No intervention	1: Mixed (+ for PA; 0 for PRAW) 2: Yes (+)	Large	NA	NA
A. Shamir and Lifshitz (2013)	1: Value-added 2: Media comparison (I-BAU)	E-book with different modes - Metacognitive guidance condition 1: Without metacognitive guidance condition	2: No intervention	2: Yes (+)	Medium	1: Metacognitive guidance (+)	NA
A. Shamir and Shlafer (2011)	Media comparison (I-BAU)	Researcher-developed e-book with different modes	No intervention	Yes (+)	Small to medium	NA	At-risk status for learning disabilities (+ with PRAW, 0 with PA)
H. Shamir et al. (2017)	Media comparison (I-BAU)	ILS Waterford "Early Reading Program"	No intervention	Mixed (+ for PA STAR; 0 for PRAW, PA DIBELS)	NA	NA	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
H. Shamir et al. (2018)	Media comparison (I-BAU)	ILS Waterford "Early Reading Program"	No intervention	Mixed (+ for LSK; 0 for PA)	Medium	NA	Special education status (0) English language learner status (0) Ethnicity (0)
Tracey and Young (2007)	Media comparison (I-BAU)	ILS Waterford "Early Reading Program" Level 1	No intervention	No (0 for PA-Lindawood, but + on other PA tests)	NA	NA	NA
van de Sande et al. (2016)	1: Value-added 2: Media comparison (A-ET/EL)	Computer (laptop) software "Schatkist met de Muis" with PA and letter knowledge learning games - Embedded EF support condition 1: Without EF support condition 2: Computer language discovery games from the same program	NA	2: No (0 for immediate post-test, but + for follow-up)	Small	1: EF Support (0 for immediate post-test, but + for follow-up)	NA
Van der Kooy-Hofland et al. (2012)	Media comparison (A-ET/EL)	Web-based computer program "Living Letters" with adaptive games E-books "Living Books" with oral narration and no printed text	NA	Mixed (in favor of games for PA; 0 for LSK)	Medium	NA	Error rate (- with PA)
Van Dijken (2023)	Value-added	E-book with print referencing tool on the SMART board E-book without print referencing tool on the SMART board	NA	NA	NA	Print referencing (+)	NA
Vanbecelaere et al. (2020)	1: Value-added 2: Media comparison (A-NET/EL)	Researcher-developed tablet reading game - Adaptive condition 1: Non-adaptive condition	2: Pen-and-paper exercises	2: No (0)	Small to medium	1: Adaptivity (0)	Pretest score (0) Home language (0) SES (0)
Watkins and Dehaene (2023)	1-2: Media comparison (A-ET/NEL; I-BAU)	Tablet game “Kalulu Phonics”	1: Tablet game “Kalulu Numbers” 2: No intervention	1-2: Mixed (0 for PA, + for LSK)	NA	NA	NA

Author (Year)	Study approach (Subcategory[a])	Educational technology and early literacy condition/s	Activities in the control condition/s	Main findings			
				Significant difference between conditions[b]	Effect size[c]	Investigated features of educational technology and its implementation[d]	Investigated learner characteristics[d]
Willoughby et al. (2015)	1-2: Media comparison (A-NET/EL)	Alphabet e-book for iPad	1: Printed alphabet book 2: Storybook	1-2: No (0)	Small	NA	Time spent oriented to book (0)
Wood et al. (2013)	Media comparison (I-BAU)	Supplemental computer-assisted (laptop with mouse) reciprocal peer tutoring using tutorials made with Microsoft PowerPoint	Media comparison	Yes (+)	NA	NA	NA

Note. AR = augmented reality; BU = bottom-up; CAI = computer-assisted instruction; EF = executive functioning; ILS = integrated learning system; PA = phonological awareness; TD = top-down.

[a] A-ET/EL = active control group with educational technology/early literacy treatment; A-ET/NEL = active control group with educational technology/non-early literacy treatment; A-NET/EL = active control group with non-technology/early literacy treatment; A-NET/NEL = active control group with non-technology/non-early literacy treatment; I-BAU = inactive control group with unclear description or business as usual.

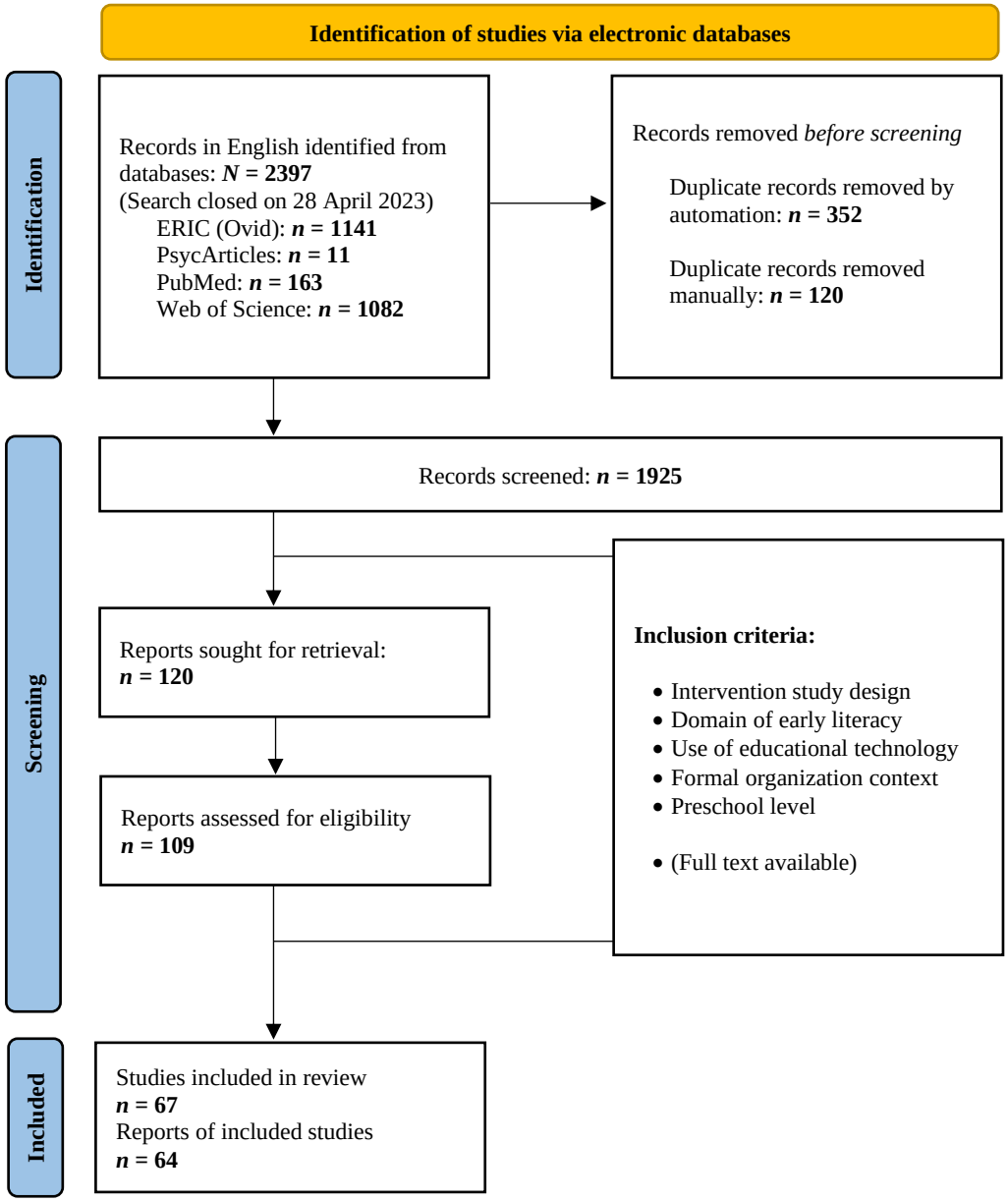
[b] 0 denotes no significant difference between conditions; + denotes a significant difference between conditions in favor of the intervention condition; - denotes a significant difference between conditions, in favor of the control condition.

[c] NA means not applicable, not reported, or unclear; for interpreting effect sizes, the basic rules of thumb are: Cohen's d = 0.20 (~small), 0.50 (~medium), 0.80 (~large); partial Eta squared = 0.01 (~small), 0.06 (~medium), 0.14 (~large).

[d] NA means not applicable or not investigated; 0 denotes no significant association between the feature/characteristic and the effectiveness of educational technology; + denotes a significant positive association between the feature/characteristic and the effectiveness of educational technology; - denotes a significant negative association between the feature/characteristic and the effectiveness of educational technology.

Figures

Figure 1. Flowchart of the Literature Search and Selection Process



Selection and Participation

There were no participants in this work.

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