Computers & Education 95 (2016) 19–35

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

The impact of digital devices vs. Pen(cil) and paper on primary school students' writing skills – A research review

Sabine Wollscheid*, Jørgen Sjaastad, Cathrine Tømte

Nordic Institute for Studies in Innovation, Research and Education, Oslo, Norway

ARTICLE INFO

Article history:
Received 22 May 2015
Received in revised form 9 December 2015
Accepted 13 December 2015
Available online 24 December 2015

Keywords:
Early writing instruction
Handwriting
Digital writing tool
Methodological performance

ABSTRACT

In the light of the continuing digital revolution in education and learning in general, and in literacy instruction in particular, the purpose of this review is to assess the emerging literature on such digital writing tools as computers and tablets compared with traditional writing tools like pen(cil) and paper, on early writing outcomes among first writers. We limited our review to studies published in international peer-reviewed journals during the last decade, within different theoretical perspectives. We identified a relatively small number of studies that can be categorized, as qualitative studies applying a case study design or within-subject design, and as quantitative studies, either quasi-experimental or cohort studies. These studies can be located within three research perspectives: 1) cognitive psychology, 2) neuroscience and learning and 3) socio-cultural theoretical perspective. While findings across the three perspectives were inconsistent, they were rather consistent within each perspective. While studies with a cognitive psychological and those with neuroscience and learning perspective point in favor of handwriting, studies with a socio-cultural perspective rather point in favor of digital writing. The studies that used a cognitive psychology and neuroscience and learning approach applied quasi-experimental or cohort designs, while studies based on a socio-cultural perspective mainly were qualitative. When analyzing the studies regarding methodological quality we found three flaws: small sample size (of quantitative studies); a lack of nesting effects; and inadequately controlling for experience for early writing. Facing an interdisciplinary research topic in rapid development, we provide some implications for further research, and suggestions in particular in terms of methodological challenges.

1. Introduction

The continuing international public and scholarly debate dealing with the future of early literacy instruction, i.e. instruction in becoming a reader and a writer, in primary school, is highly polarized. On one side, proponents of digitalization in education emphasize the possibilities of tablets and keyboards in early writing instruction and the potential of such tools to motivate students, in particular struggling learners (Genlott & Grönlund, 2013; Trageton, 2012) and students with specific learning disabilities (e.g. Berninger, Nagy, Tanimoto, Thompson, & Abbott, 2015). A meta-analysis by Morphy and Graham

* Corresponding author.
E-mail address: sabine.wollscheid@nifu.no (S. Wollscheid).

http://dx.doi.org/10.1016/j.compedu.2015.12.001
0360-1315/

(2012) for example found clearly positive effects of word processing programs on different writing outcomes, for weaker readers and writers.

On the other side, a growing literature has shown the importance of handwriting for early writers' further cognitive development (e.g., Dinehart, 2015). Handwriting appears to activate particular areas in children's brains more than other forms of fine motor manipulation tasks, like tracing or typing letters (e.g., James & Engelhardt, 2012; Kersey & James, 2013). Dinehart and Manfra (2013) found that handwriting skills more strongly could predict reading *and* math. They argue that writing letters *by hand* leads to the development of an "internal model of the alphabetic character" (ibd. 155), regarded as a foundation for further academic achievement in contrary to simply pressing on a keyboard. Writing *movements* themselves appear to be involved in the process of memorizing and the visual representation of letters, and thus, support the benefits of 'motor practice' (Vinter & Chartrel, 2010: 484) for early writing (e.g., Longcamp, Anton, Roth, & Velay, 2003; Longcamp, Zerbato-Poudou, & Velay, 2005; Vinter & Chartrel, 2010). In sum, these studies defend the practice of handwriting in early school years, as handwriting skills clearly have shown to be positively associated with further academic skills.

With this and ongoing controversy about the future of literacy instruction at primary school as a backdrop, the purpose of this article is to review internationally-published research of the last decade on the impact of pen(cil) and paper compared to digital (writing) tools (keyboards or digital tablets) in early writing instruction, on early writing outcomes.

While most of the existing literature focuses on secondary school students (e.g. Clarke & Svanaes, 2012) or university students, (Fortunati & Vincent, 2014; Taipale, 2014), relatively little attention has been paid to primary school students' early writing instruction (see also Boscolo, 2008), literature comparing digital tools with pen and paper. Among the existing literature on early writing instruction, a great number of studies exclusively deal with handwriting instruction (see for review: Dinehart, 2015; see also Accardo, Genna, & Borean, 2013; Berninger et al., 1992; Graham, Harris, & Fink, 2000; Pontart et al., 2013). Studies on early literacy instruction, covering both reading and writing – have focused mostly on early reading and its importance for further learning and academic achievement (e.g. Hattie, 2009). According to the hypotheses of the Matthew effect in reading, further learning and academic outcomes will increase to larger proportions for strong early readers; this means an increasing gap in academic achievement over time between strong and weak readers and writers (Cipielewski & Stanovich, 1992; Cunningham & Stanovich, 1997; Stanovich, 1986). Thus, paying attention to early literacy skills is crucial to foster further learning and educational progress.

In line with scholars focusing on the importance of early reading, and in line with scholars focusing on the importance of early writing (e.g., Graham, Harris, & Santangelo, 2015; Persky, Daane, & Jin, 2003), we argue that early writing skills are a prerequisite for further learning and academic achievement, particularly in the digital age (e.g., Burnett & Merchant, 2015; Merchant, 2007; Juzwik et al., 2006), a discourse with a rather shifting focus from text reception to text production. To cite Berninger et al. (2015:154): 'The Great Debate about Reading during the Industrial Age […] has been replaced with a new debate about writing in […] information age'.

As two intertwined categories of literacy, we can also understand reading and writing more widely as a social process. According to Scribner and Cole (1981: 236) literacy can be conceptualized as 'a set of socially organized practices which make use of a symbol system and a technology for producing and disseminating it. [Thus,] [l]iteracy is not simply knowing how to read and write a particular script but applying this knowledge for specific purposes in specific contexts of use.' Addressing social contexts, the wide research area of 'New Literacies Studies' (Lankshear & Knobel, 2003; Marsh, 2007) address different perspectives of literacy, from more narrow concepts of literacy limited to the dualism between reading and writing (Barton, 2007) to broader concepts including for example visual and auditory elements distinguishing between different levels and conceptions (e.g., Kress & Van Leeuwen, 2001). In our review, some studies draw on such an approach, considering the complexity of literacy needs in the digital age (e.g., Burnett & Merchant, 2015; Moje, Young, Readence, & Moore, 2000). These studies (Hultin & Westman, 2013) are included in the section of socio-cultural studies. The scope of our review, however, is limited to a more narrow approach of early writing instruction.

Focusing on students in preschool and early grades in primary school – early writers – we include studies on the use of digital writing tools including keyboards and tablet computers with touch screen technology as an alternative to pen and paper (handwriting) in early writing instruction. Our perspective is comparative, with focus on the dualism between digital writing instruction vs. traditional writing instruction by using pen-and-paper devices. Thus, we will not include in our review studies that explicitly focus on 'handwriting tools with new technologies' (Onofrei, Smaranda, Ţicău, & Şoitu, 2014) or 'pen-based systems' (Djeziri, Guerfali, Plamondon, & Robert, 2002), in other words, hybrid writing tools that combine features of digital writing tools and 'traditional' tools like pen and paper as this is beyond the scope of this review.

Further, we look at early writing outcomes like letter writing, spelling and simple sentences, in addition to subjective outcomes (writing experience). As our focus is on first writers, we do not explicitly consider higher-level writing outcomes such as planning, revising and editing (Berninger & Chanquoy, 2012). As we review a relatively new emerging field, we will include both exploratory and hypotheses-testing studies to consider both objective and subjective writing outcomes of first writers.

The next section gives a brief overview over the topic of early writing instruction by using pen and paper vs. digital tools according to the theoretical perspective applied, followed by a brief section on the method used to review the included studies. The remaining sections present the results and discuss the main findings, and finally inform the wider debate on future studies on the effect of digital devices vs. pen and paper in early literacy instruction in formal and non-formal settings.

2. Background: studies on handwriting and digital writing

From earlier research on handwriting, the evidence clearly shows a positive association between good handwriting skills and different dimensions of academic achievement, such as reading (e.g. James & Engelhardt, 2012) and memorizing skills (Dinehart, 2015). These findings are supported by studies indicating weaker associations between typing and memorizing letter outcomes compared with handwriting (e.g. Longcamp et al., 2008). Thus, the value of these studies lies in the fact that they illuminate the relation between the writing *tool* and early writing outcomes, in contrast to those on writing that have neglected the 'material aspect of writing' (Mangen & Velay, 2010). Studies on early writing may be categorized in three theoretical strands/traditions: cognitive-psychological perspectives of writing acquisition; a perspective based on neuroscience and learning; and a socio-cultural perspective (see also De Smedt & Van Keer, 2014).

2.1. Cognitive-psychological perspective

Although two different dimensions of literacy, reading and writing (see e.g. Barton, 2007) are closely connected according to the predominating approach of shared knowledge and cognitive processes. The underlying assumption is that they are constellations of cognitive processes that are dependent on knowledge representations at different linguistic levels (phonemic, orthographic, semantic, syntactic and pragmatic). To give an example, writing about text facilitates its comprehension (Fitzgerald & Shanahan, 2000), as it 'provides students with a tool for visibly and permanently recording, connecting, analyzing, personalizing, and manipulating key ideas in text' (Graham & Hebert, 2011: 712).

Studies in the tradition of the cognitive-psychological perspective (e.g. Connelly, Gee, & Walsh, 2007) often refer to the 'simple view of writing' model (Berninger et al. 2002). This model presents the multidimensional process of learning to write as a triangle, putting working memory at its center. The angles represent the three components of writing: first, low-level transcription skills, i.e. handwriting, keyboarding and spelling; second, executive functions, including conscious attention, planning, reviewing, revising, and self-regulation strategies, the two constituting the two angles at the bottom. Third, on top of the triangle are high-level text generation skills. As a foundation for further writing, *transcription skills* are developed first, enabling writers to convert ideas and spoken language into written text. For early writers, this means to develop a fluent and legible form of handwriting or fluent typing, and spelling skills. The *executive functions of writing* develop after development of transcription skills. Both transcription and executive processes support text production – the transformation of ideas into comprehensive text (Berninger et al., 2002).

According to the cognitive-psychological perspective of writing the three components draw on the same cognitive resources or 'mental operations' (Graham & Harris, 2006: 187) – the working memory – resources that are limited (Graham & Harris, 2006). An increase in resources demanded by one component (e.g. transcription) will therefore limit the amount available to other components. For first-writers, transcription skills such as handwriting or typing and spelling, require substantial resources of the working-memory. Development of transcription skills therefore is crucial in early writing instruction to help students to further develop their writing skills. While high working memory loads influence children's transcription negatively, low working memory loads will free more resources to high-level writing skills like composition and editing, thus enabling students to produce longer texts of better quality (Hayes & Berninger, 2009). To master transcription skills is the prerequisite for developing high-level writing skills. There is evidence that practice in handwriting leads to an improvement in the quality in handwritten texts (Jones & Christensen, 1999), while practice in typing leads to an improvement in the quality of typed text (Christensen, 2004). In other words, any kind of transcription mode (handwriting, typing), if mastered well, can contribute to better writing (and typing) outcomes. In sum, for beginning writers, both the mechanical demands of writing ('fine-motor skills') and perceptual demands (spelling) are supposed to lead to high working memory loads that hinder the compositional writing process (Berninger, Abbott, Augsburger, & Garcia, 2009; Flower & Hayes, 1981). Highly developed transcription skills (letter writing and spelling) among early writers, comprising fine-motor and perceptual aspects, are therefore crucial for developing more advanced writing skills (Berninger et al., 2009) including planning, translating and revising.

2.2. Neuroscience and learning perspective

Studies drawing on the theoretical perspectives based on neuroscience and learning argue that early *printing* of letters by hand influences brain activation during letter perception in a particular way compared with typing or tracing letters. Letters if printed (one single letter at a time), are hypothesized to process differently from words partly due to the individual's motor experience (James, 2010). There is evidence that writers (independent of age) who have printed the letters show a greater activation in particular left-brain regions during letter perception than those who had written the letters without printing practice (James & Engelhardt, 2012). Thus, handwriting appears to be crucial for early recruitment in letter processing in these brain regions known to underlie successful reading, and reading acquisition of young children (Kersey & James, 2013). Longcamp et al. (2005), for example, argue that writing movements – writing seen as a spatial process – appear to contribute to memorizing the shape of single letters. Letters written by a digital tool, however, differ from those written by hand, as they are 'readymades' with 'no graphomotor component involved' (Mangen & Velay, 2010). For children learning to write and read, James and Engelhardt (2012) argue that the experience of printing letters, letters that are dissimilar to those produced by accurately copying letters by typing or tracing them, may be important for emerging letter recognition and understanding.

The point is that children broaden their letter category in the developing letter recognition system, and might enhance recognition of a broader range of examples if they produce many different forms of a single letter in their own printing (by hand). To give an example, children have to learn to group letters like B and b, written with variations, under the category of letter B. Unlike recognition of other objects, for letter recognition one cannot just rely on global shape information, and cannot ignore even small changes in appearance. This example is in line with the argument that learning abstract categories enhances recognition, and that learning perceptually different examples improves category learning. From this point of view, printing letters (instead of typing or tracing them) appears to improve recognition of letters.

2.3. Socio-cultural theoretical perspective of learning

Studies informed by a *socio-cultural theoretical perspective of learning* are mostly exploratory (Clarke & Abbott, 2015; Van Leeuwen & Gabriel 2007), considering the importance of the social context in which learning occurs, in addition to the importance of earlier experiences and skills of students (Bruner, 1996; Vygotsky, 1978). From this point of view learning to read and write, i.e. literacy learning, takes place in an 'ecological' context, considering the 'interaction between individuals and their environments (Barton, 2007:29), covering formal (school and preschool) and non-formal or out-of-school contexts (e.g., Heath, 1983; Marsh, 2007), the latter including the family (e.g, Kraaykamp, 2003; Van Peer, 1991) for example. Moreover, in the contemporary digital age, new contexts for literacy have emerged, in which students read and write, for example blogs, e-mails (e.g., Merchant, 2007) and fan fiction (see e.g., Dyson, 2015; Black 2007, 2009). As previously outlined the vast literature on New Literacies, focusses on these new contexts. Nevertheless, this review draws on a more narrow definition of literacy that is limited to 'written or symbolic representation [..] mediated by new technology' (Merchant, 2007: 121) such as tablet computers or keyboards versus old technologies (pen and paper), in a formal context, the school.

According to this perspective, that combines a socio-cultural theoretical perspective and some elements of New Literacy studies, important aspects of learning include both the use of learning *tools*, such as pen and paper or the keyboard or computer, and the development of artifacts (Säljö & Moen, 2001) such as written text. An important point of this perspective is that written texts can be produced in interaction with the social environment, e.g., in interaction with teachers or peers in a classroom (e.g., Hultin & Westman, 2013).

Drawing on the assumption that the *environment or the contexts* in which literacy learning occurs, affects learning in general, and thus, some aspects of students' writing in particular, this *student-centered perspective* (Rikala, Vesisenaho, & Mylläri, 2013) takes the starting point in the learners' own experiences, their creativity and interests in becoming literate, rather than in the teachers' point of view. Thus, writing instruction can be seen as an activity in different contexts (formal, non-formal, new contexts), where children learn to read and write through social relations, for example with teachers, friends and parents, which in turn might have an impact on their writing practices in the classroom (see e.g., Genlott & Grönlund, 2013; see also: Dyson, 2015; Freedman & Delp, 2007).

Our review is not limited to a particular theoretical perspective within the emerging and dynamic field of early writing instruction. By critically reviewing the literature published during the last decade on the impact of traditional tools vs. digital tools, we specifically focus on the methodological quality or performance of the studies in light of the findings and the theoretical perspective chosen. The next section briefly describes the methods and procedures used to search, identify and critically synthesize the literature.

3. Method

Our literature review includes studies dealing with early writing instruction, setting an upper limit at primary school students aged 12. Bearing in mind an increasing focus on preschool education (Weigel, Martin, & Bennett, 2010; Wells, 1985), we do not exclude studies of preschool children from the age of three and older. Moreover, we may assume that children of that age have developed some early writing skills (Longcamp et al., 2005), and a large proportion of children at that age have been exposed to digital technologies such as tablets (Rideout, 2013).

Drawing on an emerging research field – the impact of two different writing tools on *early writing* outcomes – and drawing on the argument that early writing skills (in addition to reading skills) are the foundation for later learning outcomes, we limit our research review to studies on early writing. Thus, we exclude studies on students in secondary school (Clarke & Svanaes, 2012) and tertiary education (e.g. Fortunati & Vincent, 2014; Taipale, 2014). Further, we exclude studies on writing instruction focused on special needs education (Berninger et al., 2015; Lidström & Hemmingsson, 2014) and studies on second-language learning (Zhu, Shum, Tse, & Liu, 2015), as this is beyond the scope of our review. By limiting our review to studies published in the last ten years (2005–2015) we argue to consider the most crucial period in the development of digital tools in writing instruction and recent changes in students' learning environment (Hsin, Li, & Tsai, 2014). As digital technologies are under constant development undergoing short product cycles, we restrict the timeframe in terms of publication to the last decade to enable a certain comparability of the included studies.

Procedure: The present review article applied a systematic approach in searching and identifying the relevant studies. In the first stage, inclusion criteria and search strategy were defined: our focus was on the impact of digital writing tools (computer keyboards and tablet) vs. non-digital writing tools, i.e. pen and paper, in early writing instruction on primary school students' writing outcomes experience. We limited our search to empirical studies published in English in peer-reviewed academic journals, and conducted a search in the following international online databases: the Education

Resources Information Center (ERIC), Web of Science, ScienceDirect and Google Scholar. Further, we conducted a search in the following journals: Reading & Writing, British Journal of Educational Technology, Written Communication, Reading Research Quarterly, The Reading Teacher and Journal of Early Childhood Literacy. The search did not lead to additional studies for inclusion, than those already identified in these journals by the search in the online databases. The literature search was carried out in February 2015, and updated subsequently (last update: October 2015).

The search strategy combined relevant keywords within the topic of early writing instruction with the use of Boolean operators AND and OR and truncation * to cover variations in the keywords. Keywords were writing, digital device, tablet, computer, keyboard, iPad, pen handwriting and primary school. To give an example for a search strategy applied to the database ERIC: "writing" AND ("digital device*" OR "tablet*" OR "keyboard*" OR "computer*" OR "ipad*" OR "pen*" OR "handwriting"). Because the focus of this article is on early writing, we further limited the search to elementary education, and ended up with 211 hits in that database. A couple of hits we identified in one database were also retrieved in the remaining databases. In the ERIC database it was possible to limit the search by education level. We combined this strategy with a snowball technique starting with currently published review articles (reviews and meta-analyses), and articles published in handbooks, on the broader topic of writing instruction.

In the second stage, we screened titles and abstracts (if available) to identify possibly eligible articles, i.e. articles mentioning both the predefined comparators – pen and paper or handwriting vs. a digital writing tool – and relevant age group (preschool/primary school children). In the third stage, we read full-text articles that we identified during the first screening to include only those that fulfilled the following criteria:

1) Population: Primary school students or preschool children learning to write (early writing or pre- and primary school age writing instruction).[1]
2) Topic: Comparisons between pen and paper (handwriting) and digital tool (keyboard or tablet) used in the early writing acquisition/instruction.
3) Outcomes: Low-level writing outcomes (transcription) like letter/alphabet writing, writing of simple words and sentences, and secondary outcomes like writing enjoyment and writing experience.
4) Study design: Primary studies with quantitative and exploratory design.

In the fourth stage, we read the ten articles to describe them with respect to studying theoretical framework, population, intervention, data collection, analysis and results. The remaining section summarizes and synthesizes the studies included (results) followed by a discussion of the core findings, also in relation to the broader research field with the aim of identifying knowledge gaps and research questions for further studies.

3.1. Methodological constraints

We have chosen a sensitive rather than a specific search strategy. This means, we ended up with a relatively high number of irrelevant hits at the first stage of our search, a problem that is typical in particular in the social and educational sciences where published articles are to a lesser degree indexed by standardized terms compared with the medicine and health sciences (Hammerstrøm, Wade, Hanz, & Jørgensen, 2010).

Many full-text articles that we retrieved and read did we exclude, at the second stage, due to population and topic not matching our inclusion criteria. The articles we excluded focused either on older students (secondary or tertiary education), or exclusively on handwriting or digital writing tools.[2]

Examples of studies that we excluded in the main body of this review, due to population, were the studies carried out by Fortunati and Vincent (2014) and by Taipale (2014, 2015), who compared the impact of writing and reading on paper with writing by digital writing tools and digital reading among university students in Italy and Finland. For university students' writing, they found that students were more effective when using digital writing tools, in particular in Finland, while students preferred reading on paper. Examples of studies we excluded in the main body in this review, due to topic or different scope, are studies 1) with focus either exclusively on handwriting, for example the review by Dinehart (2015) on handwriting in early childhood and studies, or 2) with single focus on the role of digital writing tools in early writing instruction. Examples are the study by Cordero et al. (2015) on the impact of digital tools for interactive reading and writing, and the study by Gnach, Wiesner, Bertschi-Kaufmann, and Perrin (2007) on interactive writing when using computers.

At the same time, we limited our literature search to four electronic databases, in addition to snowball method, and did not search for non-published studies.

Even though we have chosen a systematic approach to retrieve, identify and analyze ten relevant studies, we do not claim to be fully inclusive. We might have overlooked relevant studies, studies accepted but not yet published in international peer-reviewed journals, or studies not identified by our search strategy based on certain keywords. Facing a time lag we are aware

[1] Primary education: We limit our study to early writing skills and, thus include pupils from the ages of 3–12 years. Studies including older students are only included in case of sub-analyses.

[2] We can assume that hybrid writing tools have been included in our search.

that the topic of this research review is changing rapidly, which is a challenge for such reviews synthesizing past studies on technologies that might have become out of date already at the point when published and later when reviewed.

Thus, rather than having the ambition to be fully inclusive with this research review, we aim to paint a picture of a dynamic and developing topic over the last decade.

4. Results

First, we present a descriptive overview of the included studies categorized under the three theoretical perspectives presented above, according to main author name, year of publication, country, title and journal name, intervention and comparator, study design and main outcomes. Second, we review the selected studies in detail, with a specific eye on study design and methods. Third, we present an overall analysis of the findings deriving from the review of the sample of our included studies and discuss these findings in the light of future studies' challenges and possibilities. Finally, we provide a discussion of the core findings in a broader context of research and by identifying further research questions.

Table 1 shows that among the ten studies published before 2010 the majority can be located within the cognitive-psychological perspective. Studies published after 2010 can be characterized either as exploratory, drawing on a socio-cultural theoretical perspective, or can be categorized under the emerging and developing perspective of neuroscience and learning.

Subsequent to the theoretical perspectives previously described, we provide a more detailed description of the single studies according to rationale and a brief description of the methods applied, including study design, sample size, temporal frame, analysis, results and main conclusions.

4.1. Review of studies with cognitive-psychological perspectives

Three studies (Connelly et al., 2007; Crook & Bennett, 2007; Read, 2007) conducted in the UK, were published in 2007. Inspired by a cognitive-psychological perspective and the simple view of writing they all assume that the quality of transcription mode, handwriting or typing, is positively associated with writing outcomes such as writing speed, and qualitative dimensions of writing. All three studies compared handwriting with typing. For typing, the Read study (2007) further distinguishes between QWERTY keyboard and pen and graphics tablet.

Given a lack of touch typing instruction, Connelly et al. (2007) hypothesized that children's written compositions produced via keyboard would be worse than produced by hand. The study sample consisted of 312 students between four and eleven years old from two primary schools located in different counties. In each of the two schools, one class with students from each year group (i.e. first to sixth class) was tested.

In each of the two primary schools, ICT lessons were taught in a separate computer suite for one hour a week; writing was integrated with ICT instruction, mainly by the use of word processor packages, while progressive typing instruction was not taught in the classroom. For both the handwriting and the typing task, students had to write a simple sentence either on paper or keyboard in two minutes, after verbal instructions on how to complete the task. Writing speed was measured as the total number of correct (handwritten or typed) letters. The findings supported the hypothesis about the inferiority of keyboarding fluency for primary students – without explicit instruction in keyboarding – compared with handwriting.

In their study, Crook and Bennett (2007) investigated the development of confidence in typing over time for primary school students between six and eleven years of age. In their study, they compare the rate of text productivity at one point in time, between two groups of students, the first using pen and paper and the second, using a keyboard.

Twelve children were randomly selected in each of three classes (second, fourth and sixth grade), from two schools from two areas with similar population. Each of the two schools had integrated ICT in most lessons although children also had access to dedicated computer suites. The test activity took place on a one-to-one basis in a quiet part of each classroom. The first simple task consisted of two examples of well-practiced text (e.g. writing one's own name). For the second task students had to reproduce a pre-typed pangram (a short sentence incorporating all alphabet letters at least once). While half of the children did handwriting before typing, the other half did the reverse. Students were asked to write as quickly as possible, but to the same standard they normally would do in class. The results indicated that typing text had no important advantage over handwriting for writing speed and fluency. For writing fluency, keyboard writing turned out to be less fluent than writing with a pen. Only for 'overlearned text' were the two media comparable.

The pilot study by Read (2007) included 18 students aged 7 to 8 using three writing modalities: pencil and paper, QWERTY keyboard, and pen and graphics tablet. Even though we do not explicitly focus on hybrid writing tools as this is beyond the scope of this review, we will in this case include the results of this condition in comparison to pencil and paper and keyboard only. All children received training in handwriting as an integrated activity in the curriculum; children got a simple training task in typing before the test, as the children had used the keyboard only based on observing other children. None of the children, however, had any experience with handwriting recognition-based technology of the graphics tablet. Students attended the experiment in small groups, the first group using pencil and paper, the second group using the keyboard and the third using a graphics tablet. According to the within-subjects study design, each of the participating students would use each technology. The writing task given was similar to one they did a year earlier. Starting with a story stimulus, children had 12 min to write, and two minutes to edit their work. For both quality (teacher assessed) and quantity of writing, the findings were in line with previous studies in favor of pencil and paper compared to keyboard and graphic tablet. Comparing keyboard

Table 1
Description of the included studies according to the theoretical perspective.

Cognitive theoretical perspective					
Authors (year)	Country	Title. Journal	Intervention/comparison	Study design/(study design category: hypothesis testing/exploratory)	Primary outcome (relevant for this review)
Connelly et al., 2007	UK	A comparison of keyboarded and handwritten compositions and the relationship with transcription speed. British Journal of Educational Psychology	Handwriting vs. typing	Quasi-experimental: 2 classes in two schools tested. (hypothesis testing)	Handwriting speed Keyboarding speed
Read, 2007	UK	A Study of the usability of handwriting recognition for text entry by children. Interacting with Computers	Pencil and paper, QWERTY keyboard, pen and graphics tablet	Within-subjects study with three conditions; a 3 × 3 Latin Square was used to determine the order in which children did the three activities. (exploratory)	Quality of writing (teacher assessed) Quantity of writing (words account)
Crook & Bennett, 2007	UK	Does using a computer disturb the organization of children's writing? British Journal of Developmental Psychology	Handwriting vs. typing	Quasi-experimental: in 3 classes of two schools in the same age, N = 12 6–11 year old children were randomly assigned to the two conditions. (hypothesis testing)	Writing speed. Fluency of writing
Berninger et al., 2009	US	Comparison of pen and keyboard transcription modes in children with and without disabilities. Learning Disability Quarterly	Handwriting vs. typing	Accelerated cohort design. (exploratory)	Reproducing letters in alphabetic order; Constructing a single sentence; Composing an essay
Neuroscience and learning					
Authors (year)	Country	Title. Journal	Intervention/comparison	Study design	Primary outcome (relevant for this review)
Longcamp et al., 2005	France	The influence of writing practice on letter recognition in preschool children: A comparison between handwriting and typing. Acta Psychologica	Handwriting vs. typing	Quasi-experimental 3 × 2 design with pre-test. (hypothesis testing)	Letter recognition
James & Engelhardt, 2012	US	The effects of handwriting experience on functional brain development in pre-literate children	Handwriting vs. typing or tracing	N = 15 were exposed (hypothesis testing)	Verbal knowledge: letter perception (tested by Bader Reading and Language Inventory)
Ouellette & Tims, 2014	Canada	The Write Way to Spell: Printing versus Typing Effects on Orthographic Learning. Frontiers in Psychology	Handwriting vs. typing	Crossed-design with respect to post-test spelling modality. (hypothesis testing)	Recognition Spelling
Sociocultural theoretical perspective					
Authors (year)	Country	Title. Journal	Intervention/comparison	Study design	Primary outcome (relevant for this review)
Van Leeuwen & Gabriel, 2007	Canada	Beginning to write with word processing: Integrating writing process and technology in a primary classroom. International Reading Association	Handwriting vs. typing	Case-study design, comprising classroom observations (1st class), informal conversations with teachers, interviews with students and student writing samples. (exploratory)	Students' attitudes to writing and computers; Writing outcomes: ideas and order, Words and sentences and conventions of language.
Genlott & Grönlund, 2013	Sweden	Improving literacy skills through learning reading by writing: The iWTR method presented and tested. Computers & Education	Integrated write to read (iWTR), using computers	Quasi-experimental; 2 × 2, N = 87 1st graders (mixed-method)	Quantitative: length (number of words) Qualitative: content, form of writing

(*continued on next page*)

Table 1 (*continued*)

Cognitive theoretical perspective					
Hultin & Westman, 2013	Sweden	Early Literacy Practices Go Digital. Literacy Information and Computer Education Journal	vs. traditional method of literacy instruction Learning to read through writing on a computers without using a pencil	Ethnographical design: over two years, a group of 1st grade teachers was observed when 'going digital'. (exploratory)	Children's texts

and graphic tablet for quantity of writing only, the study found a small and significant difference in favor of graphic tablet. At the same time, the author described students explicitly as 'quite unfamiliar' with the keyboard and the graphic tablet compared with handwriting (p. 68).

Further, the study by Berninger et al. (2009), carried out in the US, investigated the impact of two different writing modes – handwriting and typing – on the following three writing outcomes at different levels: alphabet writing, single sentence construction, and essay writing, in a sample of over 200 children with and without learning disabilities. We included this study, as it did not exclusively focus on children with learning disabilities. Building on earlier studies, showing that faster handwriting might result from more experience, this study asked if the amount and rate of handwriting or typing might vary with level of language, such as letters, sentences and longer text (essay writing). The study applied an accelerated cohort design with two cohorts. Each of the cohorts was representative of the community they were recruited from. Students in first cohort enrolled in the study when they were in first grade, and ended when they were in fifth grade. Of the 128 students enrolled at first grade, 124 re-enrolled in second grade and 119 in fourth grade. Students in the second cohort enrolled in the study when they were in third grade and ended when they were in seventh grade. Of the 113 students enrolled, 110 re-enrolled in fourth grade and 106 in sixth grade. Students' writing outcomes, including automatic letter writing, sentence construction and essay writing, were assessed when they were in second, fourth and sixth grade. For all three age groups, second, fourth and sixth grade students, and for essay writing the study consistently found that students wrote longer texts by pen compared to keyboard. For *automatic letter production*, the findings point in the opposite direction: students across all age groups wrote more letters by keyboard. For sentence construction, however, the findings are inconsistent across age: while second graders wrote more words (longer sentences) by pen, fourth and six graders wrote longer sentences by keyboard. This is an interesting study as it shows that transcription mode effects appear to depend on different level of language and on students' age.

In summary, the reviewed studies with a cognitive-psychological perspective consistently indicate an overall advantage on the impact of pen and paper to digital writing tools for early writers on different writing outcomes, both low-level and higher-level writing outcomes, a finding which probably relates to the amount of handwriting experience than instruction method. For different age groups and different language levels, however, the findings appear to be less consistent, in favor of keyboard for automatic letter production, and in favor of pencil and paper for essay writing.

4.2. Review of studies with neuroscience and learning-perspectives

Three studies draw on theoretical perspectives within neuroscience and education (Ouellette & Tims, 2014; James & Engelhardt, 2012; Longcamp et al., 2005).

The study by Longcamp et al. (2005), carried out in France, investigated the effect of dramatic motor changes by using the keyboard instead of a pen, drawing on the assumption that writing movements contribute to memorizing the shape and/or the organization of characters. The study sample included 76 children (mean age: 46 months) in three classes, in three preschools, who had not yet started to learn to read and write at school. The study compared the impact of handwriting and typing in two groups of children by testing their letter recognition performances. The study controlled for the children's age.

Based on the results of a pre-test assessing children's perceptual motor development and initial level of letter knowledge, the study divided the sample into two groups of 38 children each, matched according to age, sex, handedness, manual dexterity, educational level and letter recognition level. Further, the children of both groups were equally distributed in each classroom to prevent any teacher effect. The 38 children in each group were divided into three equivalent sub-groups of eight-month ranges. In sum, there were six groups based on the method used during learning (handwriting, typing) and age (younger, middle and older children). The aim for the children was to learn the form of twelve uppercase letters by writing them, each letter included once in four words. The learning period covered three weeks and consisted of one half-hour session per week. Children were trained in groups of four, in the presence of two researchers. Letter recognition tests were carried out directly at the end of the last learning session, and one week later. Among the older children, the handwriting group produced a higher number of correct responses compared. For the younger groups, however, there was no statistically significant difference in terms of the learning method.

Similarly, the study by James and Engelhardt (2012) carried out in the US, studied the effect of tracing, copying and handwriting letters on children's knowledge of letters, drawing on the assumption that the experience of printing non-identical copies of letters may be crucial for emerging letter recognition and understanding. Participants were fifteen, native English speaking preschoolers with pre-literate skills, between four and five years old, recruited from one community in the US. The single training session involved six conditions presented in random order. Children had to draw, trace and type capital letters eight times for each letter; they were tested in a fMRI-session, in which they passively viewed those letters they had learned in addition to letters that were not part of the training. The presentation of letters was blocked for training, and the resultant blood-oxygen level dependent (BOLD) activation was measured. The study found that the left brain region, known to be involved in reading and letter processing, was stimulated more after handwriting than typing, tracing or perceiving letters. This finding supports the argument that the printing of letters, stroke by stroke, supports children in understanding the important parts that make a letter and thus, the idea that handwriting experience is crucial for letter processing in particular (see also Bosse, Chaves, & Valdois, 2014; James, 2010; Kersey & James, 2013) and the development of fine motoric skills in general (see a comprehensive review by Graham & Weintraub, 1996).

Further, the variety in output related in letter forming might be a crucial factor involved in writing acquisition. In sum, this study adds to the research that handwriting experiences enhance letter perception, suggesting that handwriting experience is important for letter processing in the brain.

The Canadian study by Ouellette & Tims, 2014 adds to this knowledge comparing the effects of spelling practice by printing or typing on 2nd graders orthographic learning. This study investigated the role of the manual movements of printing (handwriting), in addition to the effectiveness of typing, for learning new orthographic signs. Children were exposed to ambiguously spelled 'non-words' or made-up words, to control for previous exposure. The spellings were ambiguous as the pronunciation could be matched to more than one possible spelling. While in the traditional paradigm children are tested for spelling and/or recalling when repeatedly reading these non-words, in the *modified orthographic learning paradigm* of reading, reading was replaced by repeated spelling to dictation practice. The original sample consisted of 44 English speaking 2nd graders (mean age: 7.42 years). A pre-test, post-test crossed design was applied, i.e. half of the made-up words practiced were assessed in the same modality (keyboarding, printing) as practiced, while the remaining half of the made-up words were assessed in the opposite modality. Children in one group printed List A and typed List B, while the others typed List A and printed List B. After initial literacy assessment and initial printing and typing skills at pre-test, they received a training session in which they practiced spelling the ten non-words in their assigned practice modality, either printing or typing. At two points, one and seven days later, all children were tested by a multiple-choice identification test and a spelling to dictation test. To address the effect of practice modality on orthographic learning, the study applied a repeated-measures analysis of variance (ANOVA), investigating whether performance on the recognition task differed between spelling practice groups (typing vs. printing) or testing dates. No statistically significant effect was found. In terms of interaction effects between skills (literacy, printing and typing) and practice modality, the study showed that the only interaction term to contribute significantly to the model was pre-tested typing proficiency. Thus, it appears that typing skills had an impact on learning, but only within the typing practice group.

In sum, the overall results of the reviewed studies with neuroscience and learning perspective point in favor of handwriting instruction compared to typing instruction for first-writers. In general the results support earlier findings that handwriting experience, 'the motor-graphic experience' or the 'haptics of writing' (Mangen & Velay, 2010), facilitates letter perception via processes in the brain. However, when controlling for earlier experience in handwriting there are some indications of differences on the impact of handwriting and typing on letter learning, according to age.

4.3. Review of studies with a socio-cultural theoretical perspective

Two studies (Genlott & Grönlund, 2013; Hultin & Westman, 2013) were carried out in Sweden. They both apply a writing to read approach by using digital devices in early writing and reading instruction. The Genlott and Grönlund-study applied a socio-cultural theoretical perspective; the Hultin and Westman-study was theoretically framed by New Literacy Studies.

Genlott & Grönlund, 2013 investigated the use of digital tools in social interaction. A core assumption is that the way that the (digital) tool is used in 'social interaction' (Eagle, 2012) has an influence on literacy learning. The ICT supported 'integrated Writing To Read' (iWTR) method allowed 1st grade students to use digital tools to write texts followed by a discussion with classmates and teachers with the opportunity to revise them. This approach worked with two separate, subsequent processes: first, a cognitive process by learning to read while typing on a computer; and second, a motor process by learning to write by hand with pencil. The iWTR method involved an extended social process, i.e. all writing had a purpose and an audience, and cooperation between students was facilitated. Students in the iWTR group started to write texts themselves from the beginning with the aim of gaining a pre-understanding for reading, while the keyboard supported them in writing and assisted speech synthesis. The control condition, the traditional method, required students to go through both processes in parallel, learning to read (cognitive process) and learning to spell by handwriting (motor process) (Genlott & Grönlund, 2013). This study applied a quasi-experimental study design involving a sample of 87 first graders, by comparing two groups that were taught writing by an iWTR approach by using digital writing tools in early writing instruction and two control groups receiving traditional literacy instruction. The test group of 41 students included two classes of 1st grade students; the control group of 46 students was in two classes at the same school in a Swedish municipality. Test and control groups were comparable in different characteristics. The test period comprised one year, from August 2010 to June 2011. The three teachers who worked with the test group, however, did not get any specific teacher training before the project.

The following two hypotheses tested are related to our review: 1) The sequencing of two processes of literacy acquisition, learning to read and to write by hand, facilitates reading and writing skills for all students over a period of the first school year. 2) ICT tools might improve performance during the process of learning to read and write. Both quantitative and qualitative outcomes were studied, measured by number of words, and written content. The authors found that texts produced in the test group were longer, and they had a clearer story with a more logical flow of events described than the control group students. According to the teachers' assessment (based on experience), a majority of the students in the test group had already at the end of 1st grade achieved writing skills required by national tests to be taken in 3rd grade. However, limitations included that there was no strict comparison (e.g. on word count) with texts produced in the control group, which is meaningful as there simply were no comparable texts from this group (p. 103) and the small sample size of the test group. Referring to that study as a small-scale study, the authors mention a study to be published based on a larger sample.

Applying a case study design, Van Leeuwen and Gabriel (2007) explored the impact of using a word processor on the writing of beginning writers. The unit of analysis was a first grade class in a rural school in a province in Canada. Of particular

interest for this review, was the development of the particular understanding of the multiple factors involved when early writers use a word processor. The study collected a wide range of data from classroom observations, informal conversations with the teacher, field visits, student interviews and student writing samples. Thirteen students, six boys and seven girls, participated in the study; all of them had previous experience with the computer either at home or in kindergarten. Throughout the school year, every three weeks, researchers visited the classroom for 40–90 min. During these visits, they observed the students in their use of word processor or pencil and paper when writing. Further, samples of texts (handwritten and word-processed) were collected and informal conversations held with teachers. The study found that students were enthusiastic writers both online and offline. Interviewed about which kind of writing tool they preferred, three quarters preferred the computer. Some were concerned about the effort of writing by hand. Students with strong writing skills working in a notebook with a pencil were frequently able to sustain their focus on the writing task longer than when they worked with a computer. Second, the study revealed that word-processed and handwritten texts were of similar quality. Word processors did not reduce the quality of writing in terms of the three criteria: ideas and order; words and sentences; and conventions of language. Further, writing samples composed with pencil and paper were generally longer than those composed with computer (word processors). The authors conclude that neither composition tool is able to serve all the needs of novice writers, but that word processors rather are 'tools that can complement the range and type of writing activities in elementary school classrooms. The leadership role played by the classroom teacher in implementing word processing in the writing curriculum is a critical component in determining the felicitous use of this tool' (427).

Theoretically framed by New Literacy Studies, the study by Hultin and Westman (2013) seeks to contribute to an overall understanding of the way in which digitalization influences early literacy practices in terms of literacy teaching and use of text genres in digitalized writing, situated in the school context. In this study, the term 'digitalization' means the introduction of new digital writing tools such as classroom computers and the use of a specific instruction method, 'learning to read through writing'.

The research question of interest for our review addressed the way of how possible changes in digitalized literacy teaching would affect children's text production. Applying an ethnographical design the study followed first grade teachers over the course of two years in their way of 'going digital' and looking at children's texts as an outcome of interest. Several data collection methods were applied: teacher observation, qualitative interviews with teachers, classroom observations, and 471 texts from 12 different children over a two-year period, six from each of the two observed classes. One finding was that children produced whole texts at an earlier stage *after* digitalization, i.e., after the introduction of the computer and of the new instruction method. Second, children were able to produce much longer texts without mastering all the letters at an earlier stage. The authors conclude that computer writing is simpler than handwriting, since it does not demand highly developed motor skills. Furthermore, digitalization seems to play a crucial role in changing the conditions for writing and rewriting texts for children who appear to have 'more agency' when writing texts on the computer as they can more easily revise and reorganize their texts.

In summary, studies with a socio-cultural theoretical perspective and studies originally framed by New Literacy Studies draw on a different instruction approach, 'learning to read by writing', and by introducing the computer/keyboard as an alternative writing tool compared to pen and paper. The reviewed studies were mostly exploratory in their approach, using a qualitative study design. In general, they indicate that children having used the computer at an early stage produce longer text, without mastering all the letters at that stage. At the same time, the key point raised by one of the studies is that the critical factor in early writing instruction is the ways of implementing the tools and the writing curriculum and to a lesser extent the tools themselves.

5. Synthesis of findings and discussion

Drawing on the controversial debate on the future of first-writing instruction in primary school, we have in this article reviewed international studies published during the last decade that investigated the impact of two different writing tools, pencil and paper vs. digital writing tools, or writing instruction modes, handwriting and typing, on early writing outcomes. Our overall aim was to paint a picture of a dynamic and developing topic over the last decade, to identify some general trends and provide some implications for further research.

In the following paragraphs, we provide a synthesis of the main findings across three different theoretical perspectives we identified, and discuss the main findings of our review in light of methodological issues, and the broader development of the research field – writing instruction in the digital information age. Finally, we give some suggestions for further literature reviews.

Drawing on a rather narrow research question, we identified ten studies comparing the impact of writing tools – pen and paper on the one hand, and one or more digital writing tools (such as keyboard computer), on the other. We categorized the ten studies under three theoretical perspectives, namely, the cognitive-theoretical perspective, the perspective of neuroscience and learning and the socio-cultural theoretical perspective.

First, overall, the results of the reviewed studies are inconsistent across the three different perspectives, and do not allow any conclusion on the impact in favor of either a digital writing tool or pen(cil) and paper on early writing outcomes. Second, within each theoretical perspective, however, we found consistent patterns across studies, either in favor of handwriting (tools) (cognitive-theoretical perspective, perspective of neuroscience and learning) or digital writing tools (socio-cultural perspective; New Literacy Studies). Third, regarding year of publication, we elicited the following trends: results of earlier

published studies rather point in favor of traditional writing tools like pen and paper on early writing outcomes, given that students were mostly trained in handwriting instruction (Berninger et al., 2009; Connelly et al., 2007; Crook & Bennett, 2007; James & Engelhardt, 2012; Longcamp et al., 2005); later dated studies do not reveal any clear difference (Ouellette & Tims, 2014), or they point in favor of digital writing tools (Genlott & Grönlund, 2013). In particular, more exploratory studies, combining qualitative and quantitative methods, and in the socio-cultural theoretical tradition or in the field of New Literacy Studies, rather indicate a positive impact of digital tools on students' writing experiences and motivation (Genlott & Grönlund, 2013; Hultin & Westman, 2013; Van Leeuwen & Gabriel, 2007).

Assessing the *methodological performance* of the included studies, we identified some typical methodological issues limiting the possibility to generalize the findings of the studies, and further, to conduct more detailed quantitative analysis.

First, most studies include only small sample sizes (N): among the reviewed articles, only four studies have a sample size greater than 50 (72, 87, 241 and 312), even when the control groups are included (Berninger et al., 2009; Connelly et al., 2007; Crook & Bennett, 2007; Genlott & Grönlund, 2013). Small sample sizes does not imply that the research is inapplicable; to generalize quantitative studies, however, the studies would benefit from having larger sample sizes.

Second, none of the included studies applying a hypothesis testing study design considered nesting effects. A considerable amount of the variance in school research can be explained by differences between schools and classes, not only by differences between students. Students in the same classroom tend to be more similar than randomly selected students, so estimates of differences appear larger than they actually are. When writing tests were administered by using different test formats (comparisons between pen/paper and digital devices), any difference in advantage of traditional teaching may be explained by the fact that students have had longer experience in handwriting. Thus, providing students with a digital device for a limited time period does not equate to the weeks, months and years of pen/paper experience.

6. Conclusion and implications for further studies

As demonstrated in this review, the benefits of replacing handwriting by typing in early writing instruction lack consistent evidence.

On the one side, earlier published studies, mostly within the field of cognitive psychology, show an advantage in using traditional writing tools like pen and paper compared with typing in early writing instruction (Connelly et al., 2007; Crook & Bennett, 2007), which might be due to children receiving more handwriting instruction than typing instruction in early years. On the other side, studies published more recently are either inconclusive in their results (Ouellette & Tims, 2014), or, if belonging to a socio-cultural theoretical tradition (Genlott & Grönlund, 2013) or New Literacy Studies (Hultin & Westman, 2013), their results point in the opposite direction, in favor of digital writing tools, for early writing instruction. To provide another example for older students, The Nations Report Card (NCES 2012) has shown that students in eight-grade using computers to draft and revise their writing score higher on standardized evaluations assessed with criteria that mostly reflect traditional literacy standards.

When reviewing a small number of studies across different theoretical traditions, we elicited one interesting finding in the study of Berninger et al. (2009) that might be the basis for developing further and more specific research questions:

Comparing handwriting and typing across different age groups and for different levels of language (alphabet writing, sentence composing and essay writing) Berninger et al. (2009) found that students in elementary school, independent of age, wrote more letters automatically by keyboard, while they wrote longer essays by pen.

In particular, studies with a cognitive psychological perspective and studies with a neuroscience and learning perspective appear to draw on rather traditional concepts of writing and reading in a 'linear fashion' (Graesser & McNamara, 2012) and in solitary, while studies in the socio-cultural traditions and New Literacy studies appear to draw on a student-centered perspective, and a broader concept of literacy including dimensions such as interactive writing and reading (Genlott & Grönlund, 2013; Hultin & Westman, 2013) in addition to classical dimensions of early writing.

Given the inconsistent findings across different theoretical perspectives over time on the impact of digital tools compared with pen and paper in early writing instruction, further studies might further elaborate the impact of handwriting and typing on such single aspects in early writing as memorizing, letter writing, structuring and writing speed in different writing environments. Literacy including writing and reading is more complex today than several decades ago. This has implications for further research that should take into account that complexity by drawing on a broader range of writing tools and broader definitions of writing in literacy instruction.

In this review, we have excluded those studies that exclusively focus on the impact of (different) digital tools for literacy instruction. Building on our research strategy, further review studies, might in particular focus on these kind of studies, such as Cordero et al. (2015) and Gnach et al. (2007), and the impact of digital tools on writing and reading instruction in primary education.

Acknowledgments

The authors would like to thank their colleagues at NIFU Cay Gjerustad, Bjørn Stensaker, Vibeke Opheim and Rune Reiling, and Nalini Silje Løver, master's student at the University of Oslo, for useful comments and recommendations. The article was funded by NIFU's internal grant (project number 12820530-67).

Appendix

Table 2 categorizes and synthesizes the studies according to their methodological approach/approach including a more specified description of the study including study design, tests used, analyses and results and some authors' comments.

Table 2
Description of the included studies with focus on their methods used.

Basic info	Test	Analysis/results	Authors' comment
Studies with cognitive-psychological perspective			
Connelly et al., *2007* Quasi-experimental: 2 classes in two schools tested. N Study 1: Two schools, one class from each year group (age 4–11), a total of 312 students. Schools analyzed together due to similarities in handwriting & typing speed. N Study 2: Subset of the 48 year 5 + 6 students in Study 1. They had 1 h ICT lesson per week for all, practiced word processors.	Study 1: Handwriting task: 2 min to copy a text. Keyboard task: 2 min to copy a text. Measure: Number of correct letters produced. Study 2: The Weschler Objective Language Dimensions written expression subscale: 15 min free writing. Provides 6 subscores. Students wrote 2 pieces: using word and using pencil.	Study 1: Perfect inter-rater reliability. Differences in mean scores between students in same school year, 95% confidence intervals utilized. Significant interaction between school year and handwriting/typing. Study 2: Good inter-rater reliability. Mean scores of each of the 6 subscores were computed for Word and for pencil. ANOVA confirms hypothesis.	Nesting effects missing. Little ICT compared to handwriting in school. Measures "what is taught" more than "what is efficient". Study 1: Handwriting is faster than typing in this age group. Study 2: Handwriting essay quality is superior to keyboarded essay quality (one standard deviation).
Crook & Bennett, 2007 Quasi-experimental: in 3 classes of two schools in the same area, 12 6–11 year old children were randomly assigned to the two conditions. N: 72 children from two schools. Two year 2 classes, two year 4 classes and two year 6 classes. Both schools had integrated ICT into most lessons. Pupils also used computer suites. "All these children had long experience of using computers in class.	Students wrote free texts and panagrams (sentence with all letters in alphabet) using keyboard on one and pen-on-tablet on the other.	ANOVA of school*year*pen/keyboard. Free text: Significant diff. in writing speed in favor of pen in year 2 classes: Lower median time to produce letters (no overlap in 95% conf.int). Full overlap conf.int for year 4 and 6 classes. Sig.diff in writing fluency in favor of pen in all classes, no overlap in 95% conf.int. Panagrams: Sig.diff in speed and fluency in favor of pen in all groups. (Makes use of full keyboard – also the least used letters) Higher number of looks at the panagram draft during writing with keyboard. (Probably due to the relationship with accumulated writing time)	Nesting effects missing. Little ICT compared to handwriting in school. Measures "what is taught" more than "what is efficient". Concludes that "keyboards appear to impede the executive aspect of writing. These observations are significant" and that children must be learnt the touch method and made more familiar with keyboard use.
Read, 2007 Within-subjects study with three conditions; a 3 × 3 Latin Square was used to determine the order in which children did the three activities. N: 18 children aged 7–8. All in the same class. They had 1 h pencil writing every day. All had used keyboard, but	Wrote 3 free texts, using pencil, keyboard and digital pen on tablet (text recognition), in random order. Quality was teacher assessed.	ANOVA "revealed" sig.mean effect on quality and quantity for input method, in favor of pencil. T-tests "revealed" no sig.diff between keyboard and dig.pen. No sig.diff in what the children thought was most fun.	Inapplicable results. It turned out that only one student had used keyboard before. It turned out that they did not know how to use the "smileyometer" to asses fun activities. It turned out that not all had understood the use of text recognition.

(*continued on next page*)

Table 2 (*continued*)

Basic info	Test	Analysis/results	Authors' comment
Studies with cognitive-psychological perspective			
did not know it well (e.g. capitalizing), some training was provided. None had not used text recognition before. Some training given before test. (OBS: Had been writing fables in their exercise books before)			
Berninger et al., *2009* Accelerated cohort design. N: 241 children: 128 in first grade (119 were present in fourth grade) and 113 in third grade (106 were present in sixth grade). Recruitment through letters to parents in a US school district.	Three writing tasks each year: The alphabet, a sentence and an essay, all tasks with both pencil and keyboard. They had 10 min to write the essays.	Inter-rater reliability of 0.94. Wrote more letter by keys than pen in the 15 s alphabet task and more words in the sentence, but less words in the 10 min essay. With regard to secs/full alphabet, pen was faster, and 2 graders in particular used less seconds per word in sentence and essay using pen than keys. At the text level, pens had an advantage over keyboards, perhaps due to fluency (which correlates to quality). Reports differences using partial eta2, and most differences are considered large.	Nesting effects missing. Little ICT compared to handwriting in school. Measures "what is taught" more than "what is efficient".
Studies with neuroscience and education-perspectives			
Longcamp et al., *2005* N: Two groups of 38 3–5 year olds, selected to have equal pre-test scores in letter recognition: Among groups of four visually similar symbols, the children were to identify the letters.	During letter training, the typing children typed the presented letter on a 15-key-keyboard. The handwriting children, with the same input, would use a pen to draw the presented letter. Immediately after (T1) and one week later (T2), the letter recognition test used was repeated.	Few differences were identified among the youngest and middle children: They scored quite similar on the pre-test, T1 and T2. Among the oldest, the handwriting group experienced a significant increase in correct responses from pre-test to T1. The effect did not decline during the first week (T2).	Nesting effects missing.
James & Engelhardt, 2012 N: 15 pre-literate 4–5 year olds	Children were shown letters and shapes and were to print/draw, trace (dot-to-dot) or type what they saw. Four letters and four shapes were produced eight times before the next of the three stimuli. Later, they assessed letter identification and word discrimination using validated test batteries.	Through brain scanning, they conclude that different processes take place during printing/drawing, tracing and typing. Printing stimulated all areas more than typing, and printing stimulated other areas as well. This includes activation of the brain's network for reading and writing.	We do not have the competence to evaluate the measures applied in this study: Neuroscience uses measures like "Talairach peak" and "Total voxel size".
Ouellette & Tims, 2014 N: 40 students in 2 grade (mean: 7.5 years old)	They were introduced to 10 novel non-words, some practiced these by printing and some by typing (randomly assigned, 5 typing and 5 printing). Their	Using ANOVA, no significant differences were detected. (Validated trough multilevel analysis).	Minimal differences (most often in favor of handwriting) might have been significant in a large scale study. (These differences would still be too small to hold any interest)

Table 2 (*continued*)

Basic info	Test	Analysis/results	Authors' comment
Studies with cognitive-psychological perspective			
	recognition and spelling of these non-words were tested 1 (T1) and 7 (T2) days later: They were presented to four words: the non-word and three similar, and should mark the correct one.		
Socio-cultural theoretical perspective			
Van Leeuwen & Gabriel, 2007 N: 13 students in 1 grade. All had previous experience with PC.	Through classroom observations every third week, including 10 min interviews with 4 students, informal teacher interviews and collections of written works, data were collected over a year.	These students wrote longer texts with pencil than a word processor. The quality was considered as being similar.	This study has value as an exploration of how beginning writers might interact with a word processor.
Genlott & Grönlund, 2013 N: 87 students in 1 grade: 41 in test group (two classes) and 46 in control group (two classes). All in the same school. The test group applied the iWTR method during the entire grade 1 (computer writing/letter and word sound recognition before handwriting of letters/words)	Standardized pre-test by National School Board and similar post-test (writing) + a post-test named H4 (reading; how many words read correctly in one minute) Test group measured in H4 before summer (1 grade) and the control group after summer (2 grade).	Reading: No differences in# students >35 words/min, some difference in favor of test group in# students >55 words/min. Systematic testing of writing skills were not conducted, but "we found that texts produced in the test group were (much) longer, they had a clearer story with a more logical flow (…) a majority of the students in the test group had already at the end of grade 1 achieved writing skills required by the national tests to be taken in grade 3."	Nesting effects missing. Some difference in fast readers. No documented difference in writing. Anecdotic results probably due to the test group being tested digitally.
Hultin & Westman, 2013 N: 12 students; two from each of the six observed classes (1 grade) The students were "Going digital" in their first literacy learning.	The researchers collected texts from 12 students over one year, and made observations and interviews with teachers in the six classes. No control group – only the teachers' impressions of change.	"Not only are whole texts produced at an earlier stage than before, but the texts produced are also longer and more multimodal" is the teachers' impression. The students appreciated how Word marks spelling and how it is easier to correct without ruler.	No actual results to comment on. Anecdotal evidence.

References

Accardo, A. P., Genna, M., & Borean, M. (2013). Development, maturation and learning influence on handwriting kinematics. *Human Movement Science, 32*(1), 136–146.

Barton, D. (2007). *Literacy: An introduction to the ecology of written language*. Malden: Blackwell.

Berninger, V. W., Abbott, R. D., Augsburger, A., & Garcia, N. (2009). Comparison of pen and keyboard transcription modes in children with and without learning disabilities. *Learning Disability Quarterly, 32*(3), 123–141.

Berninger, V., & Chanquoy, L. (2012). What writing is and how it changes across early and middle childhood development. A multidisciplinary perspective. In E. L. Grigorenko, E. Mambrino, & D. D. Preiss (Eds.), *Writing. A mosaic of new perspectives* (pp. 65–84). New York: Psychology Press, Taylor & Francis Group.

Berninger, V. W., Nagy, W., Tanimoto, S., Thompson, R., & Abbott, R. D. (2015). Computer instruction in handwriting, spelling, and composing for students with specific learning disabilities in grades 4–9. *Computers & Education, 81*, 154–168.

Berninger, V. W., Vaughan, K., Abbott, R. D., Begay, K., Coleman, K. B., Curtin, G., et al. (2002). Teaching spelling and composition alone and together: implications for the simple view of writing. *Journal of Educational Psychology, 94*(2), 291–304.

Berninger, V., Yates, C., Cartwright, A., Rutberg, J., Remy, E., & Abbott, R. (1992). Lower-level developmental skills in beginning writing. *Reading and Writing. An Interdisciplinary Journal, 4*, 257–280.

Black, R. W. (2007). Fanfiction writing and the construction of space. *E-Learning and Digital Media, 4*(4), 384–397.
Black, R. W. (2009). Online fan fiction and critical media literacy. *Journal of Computing in Teacher Education, 26*(2), 75–80.
Boscolo, P. (2008). Writing in primary school. In C. Bazerman (Ed.), *Handbook of research of writing. History, society, school, individual, text* (pp. 293–309). New York: Lawrence Erlbaum.
Bosse, M.-L., Chaves, N., & Valdois, S. (2014). Lexical orthography acquisition: is handwriting better than spelling aloud? *Frontiers in Psychology, 5*.
Bruner, J. (1996). *The culture of education*. Cambridge Massachusetts: Harvard University Press.
Burnett, C., & Merchant, G. (2015). The challenge of 21st-century literacies. *Journal of Adolescent & Adult Literacy, 59*(3), 271–274.
Christensen, C. A. (2004). Relationship between orthographic-motor integration and computer use for the production of creative and well-structured written text. *British Journal of Educational Psychology, 74*(4), 551–564.
Cipielewski, J., & Stanovich, K. E. (1992). Predicting growth in reading ability from children's exposure to print. *Journal of Experimental Child Psychology, 54*, 74–89.
Clarke, L., & Abbott, L. (2015). Young pupils', their teacher's and classroom assistants' experiences of iPads in a Northern Ireland school:"Four and five years old, who would have thought they could do that?". *British Journal of Educational Technology*. http://dx.doi.org/10.1111/bjet.12266.
Clarke, B., & Svanaes, S. (2012). *One-to-one tablets in secondary schools: An evaluation study stage one* [retrieved January 16, 2015]. fromhttp://tabletsforschools.org.uk/wp-content/uploads/2012/12/FKY-Tablets-for-Schools-Stage-2-Full-Report-July-2013.pdf.
Connelly, V., Gee, D., & Walsh, E. (2007). A comparison of keyboarded and handwritten compositions and the relationship with transcription speed. *British Journal of Educational Psychology, 77*, 479–492.
Cordero, K., Nussbaum, M., Ibaseta, V., Otaíza, M. J., Gleisner, S., González, S., et al. (2015). Read Create Share (RCS): a new digital tool for interactive reading and writing. *Computers & Education, 82*, 486–496.
Crook, C., & Bennett, L. (2007). Does using a computer disturb the organization of children's writing? *British Journal of Developmental Psychology, 25*(2), 313–321.
Cunningham, A., & Stanovich, K. (1997). Early reading acquisition and its relation to reading experience and ability 10 years later. *Developmental Psychology, 33*(6), 934–945.
De Smedt, F., & Van Keer, H. (2014). A research synthesis on effective writing instruction in primary education. *Procedia – Social and Behavioral Sciences, 112*, 693–701.
Dinehart, L. H. (2015). Handwriting in early childhood education: current research and future implications. *Journal of Early Childhood Literacy, 15*(1), 1–22.
Dinehart, L. H., & Manfra, L. (2013). Associations between early fine motor development and later math and reading achievement in early elementary school. *Early Education and Development, 24*(2), 138–161.
Djeziri, S., Guerfali, W., Plamondon, R., & Robert, J. (2002). Learning handwriting with pen-based systems: computational issues. *Pattern Recognition, 35*(5), 1049–1057.
Dyson, A. H. (2015). Playing with textual toys: Popular culture and childhood writing. In J. Flood, B. Heath, & D. Lapp (Eds.), *Handbook of research on teaching literacy through the communicative and visual arts* (Vol. II, pp. 461–470). New York: Routledge. A Project of the International Reading Association.
Eagle, S. (2012). Learning in the early years: social interactions around picturebooks, puzzles and digital technologies. *Computers & Education, 59*(1), 38–49.
Fitzgerald, J., & Shanahan, T. (2000). Reading and writing relations and their development. *Educational Psychologist, 35*(1), 39–50.
Flower, L. S., & Hayes, J. R. (1981). A cognitive process theory of writing. *College Composition and Communication, 32*, 365–387.
Fortunati, L., & Vincent, J. (2014). Sociological insights on the comparison of writing/reading on paper with writing/reading digitally. *Telematics and Informatics, 31*, 39–51.
Freedman, S. W., & Delp, V. K. (2007). Conceptualizing a whole-class learning space: a grand dialogic zone. *Research in the Teaching of English*, 259–268.
Genlott, A. A., & Grönlund, Å. (2013). Improving literacy skills through learning reading by writing: the iWTR method presented and tested. *Computers & Education, 67*(9), 98–104.
Gnach, A., Wiesner, E., Bertschi-Kaufmann, A., & Perrin, D. (2007). Children's writing processes when using computers. Insights based on combining analyses of product and process. *Research in Comparative and International Education, 2*(1), 13–28.
Graesser, A., & McNamara, D. (2012). Reading instruction: technology based supports for classroom instruction. In C. Dede, & J. Richards (Eds.), *Digital teaching platforms: Customizing classroom learning for each student* (pp. 71–87). New York, NY: Teachers College Press.
Graham, S., & Harris, K. R. (2006). Strategy instruction and the teaching of writing. A meta-analysis. In C. A. MacArthur, S. Graham, & J. Fitzgerald (Eds.), *Handbook of writing research* (pp. 187–207). New York: The Guilford Press.
Graham, S., Harris, K. R., & Fink, B. (2000). Is handwriting causally related to learning to write? Treatment of handwriting problems in beginning writers. *Journal of Educational Psychology, 92*(4), 620–633.
Graham, S., Harris, K. R., & Santangelo, T. (2015). Research-based writing practices and the common core. Meta-analysis and meta-synthesis. *The Elementary School Journal, 115*(4), 498–522.
Graham, S., & Hebert, M. (2011). Writing to read: a meta-analysis of the impact of writing and writing instruction on reading. *Harvard Educational Review, 81*(4), 710–744.
Graham, S., & Weintraub, N. (1996). A review of handwriting research: progress and prospects from 1980 to 1994. *Educational Psychology Review, 8*(1), 7–87.
Hammerstrøm, K., Wade, A., Hanz, K., & Jørgensen, A. M. K. (2010). *Searching for studies: Information retrieval methods group policy brief*. Oslo, Norway: The Campbell Collaboration. http://dx.doi.org/10.4073/pb.2009.1.
Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. New York: Routeledge.
Hayes, J. R., & Berninger, V. W. (2009). Relationships between idea generation and transcription. How the act of writing shapes what children write. In C. Bazerman, R. Krut, K. Lunsford, S. McLeod, S. Null, P. Rogers, et al. (Eds.), *Traditions of writing research* (pp. 166–180). New York, London: Routeledge.
Heath, S. (1983). *Ways with words: Language, life, and work in communities and classrooms*. Cambridge Univ Press.
Hsin, C.-T., Li, M.-C., & Tsai, C.-C. (2014). The influence of young children's use of technology on their learning: a review. *Journal of Educational Technology & Society, 17*(4), 85–99.
Hultin, E., & Westman, M. (2013). Early literacy practices go digital. *Literacy Information and Computer Education Journal (LICEJ), 4*(2), 1005–1013.
James, K. H. (2010). Sensori-motor experience leads to changes in visual processing in the developing brain. *Developmental Science, 13*(2), 279–288.
James, K. H., & Engelhardt, L. (2012). The effects of handwriting experience on functional brain development in pre-literate children. *Trends in Neuroscience and Education, 1*(1), 32–42.
Jones, D., & Christensen, C. A. (1999). Relationship between automaticity in handwriting and students' ability to generate written text. *Journal of Educational Psychology, 91*(1), 44–49.
Juzwik, M. M., Curcic, S., Wolbers, K., Moxley, K. D., Dimling, L. M., & Shankland, R. K. (2006). Writing into the 21st century an overview of research on writing, 1999 to 2004. *Written Communication, 23*(4), 451–476.
Kersey, A. J., & James, K. H. (2013). Brain activation patterns resulting from learning letter forms through active self-production and passive observation in young children. *Frontiers in Psychology, 4*(567). http://dx.doi.org/10.3389/fpsyg.2013.00567.
Kraaykamp, G. (2003). Literary socialization and reading preferences. Effects of parents, the library, and the school. *Poetics, 31*, 235–257.
Kress, G., & Van Leeuwen, T. (2001). *Multimodal discourse: The modes and media of contemporary communication*. London: Edward Arnold.
Lankshear, C., & Knobel, M. (2003). *New literacies: Changing knowledge and classroom learning* (2nd ed.). Philadelphia: Open University Press.
Lidström, H., & Hemmingsson, H. (2014). Benefits of the use of ICT in school activities by students with motor, speech, visual, and hearing impairment: a literature review. *Scandinavian Journal of Occupational Therapy*, 1–16.
Longcamp, M., Anton, J.-L., Roth, M., & Velay, J.-L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *Neuroimage, 19*(4), 1492–1500.

Longcamp, M., Boucard, C., Gilhodes, J.-C., Anton, J.-L., Roth, M., Nazarian, B., et al. (2008). Learning through hand-or typewriting influences visual recognition of new graphic shapes: behavioral and functional imaging evidence. *Journal of Cognitive Neuroscience, 20*(5), 802–815.
Longcamp, M., Zerbato-Poudou, M. T., & Velay, J. L. (2005). The influence of writing practice on letter recognition in preschool children: a comparison between handwriting and typing. *Acta Psychologica, 119*(1), 67–79.
Mangen, A., & Velay, J.-L. (2010). Digitizing literacy: reflections on the haptics of writing. In M. H. Zadeh (Ed.), *Advances in haptics*. http://dx.doi.org/10.5772/8710. Available from: http://www.intechopen.com/books/advances-in-haptics/digitizing-literacy-reflections-on-the-haptics-of-writing.
Marsh, J. (2007). New literacies and old pedagogies: recontextualizing rules and practices. *International Journal of Inclusive Education, 11*, 267–281.
Merchant, G. (2007). Writing the future in the digital age. *Literacy, 41*(3), 118–128.
Moje, E. B., Young, J. P., Readence, J. E., & Moore, D. W. (2000). Commentary: reinventing adolescent literacy for new times: perennial and millennial issues. *Journal of Adolescent & Adult Literacy*, 400–410.
Morphy, P., & Graham, S. (2012). Word processing programs and weaker writers/readers: a meta-analysis of research findings. *Reading and Writing, 25*(3), 641–678.
Onofrei, C.,S., Ţicău, A., & Şoitu, L. (2014). Training for new technologies. handwriting with new technologies. *Procedia – Social and Behavioral Sciences, 142*, 781–785. http://dx.doi.org/10.1016/j.sbspro.2014.07.616.
Ouellette, G., & Tims, T. (2014). The write way to spell: printing versus typing effects on orthographic learning. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.00117.
Persky, H. R., Daane, M. C., & Jin, Y. (2003). *The Nation's report Card: Writing 2002, NCES 2003–529*. Washington DC: U.S. Department of Education. Institute of Education Sciences. National Center for Education Statistics.
Pontart, V., Bidet-Ildei, C., Lambert, E., Morisset, P., Flouret, L., & Alamargot, D. (2013). Influence of handwriting skills during spelling in primary and lower secondary grades. *Frontiers in Psychology, 4*.
Read, J. C. (2007). A study of the usability of handwriting recognition for text entry by children. *Interacting with Computers, 19*(1), 57–69.
Rideout, V. (2013). *Zero to eight: Children's media use in America 2013. A Common Sense Media research study*. San Francisco, CA: Common Sense Media.
Rikala, J., Vesisenaho, M., & Mylläri, J. (2013). Actual and potential pedagogical use of tablets in schools. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments, 9*(2), 113–131.
Säljö, R., & Moen, S. (2001). *Læring i praksis: Et sosiokulturelt perspektiv*. Oslo: Cappelen akademisk.
Scribner, S., & Cole, M. (1981). *The psychology of literacy* (Vol. 198). Cambridge, MA: Harvard University Press.
Stanovich, K. E. (1986). Matthew effects in reading: some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21*(4), 360–407.
Taipale, S. (2014). The affordances of reading/writing on paper and digitally in Finland. *Telematics and Informatics, 31*, 532–542.
Taipale, S. (2015). Bodily dimensions of reading and writing practices on paper and digitally. *Telematics and Informatics, 32*(4), 766–775.
Trageton, A. (2012). At skrive sig til læsning [Writing to read]. *Lesepedagogen, 2*, 16–22.
Van Leeuwen, C. A., & Gabriel, M. A. (2007). Beginning to write with word processing: integrating writing process and technology in a primary classroom. *International Reading Association*, 420–429.
Van Peer, W. (1991). Literary socialization in the family: a state of the art. *Poetics, 20*, 539–558.
Vinter, A., & Chartrel, E. (2010). Effects of different types of learning on handwriting movements in young children. *Learning and Instruction, 20*(6), 476–486.
Vygotsky, L. S. (1978). *Mind in society. The development of higher psychological processes*. Cambridge, Massachusetts: Harvard University Press.
Weigel, D., Martin, S., & Bennett, K. (2010). pathways to literacy: connections between family assets and preschool children's emergent literacy skills. *Journal of Early Childhood Research, 8*(1), 5–22.
Wells, G. (1985). Preschool literacy-related activities and success in school. In D. Olson, N. Torrance, & A. Hildyard (Eds.), *Literacy, language and learning* (pp. 229–255). Cambridge: Cambridge University Press.
Zhu, Y., Shum, M. S.-K., Tse, B. S.-K., & Liu, J. J. (2015). Word-processor or pencil-and-paper? A comparison of students' writing in Chinese as a foreign language. *Computer Assisted Language Learning*, 1–22. http://dx.doi.org/10.1080/09588221.2014.1000932.