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Longitudinal assessment of digital literacy in children: Findings from a large Dutch single-school study

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ABSTRACT

This article reports on a three-year longitudinal study that portrayed the development of children's digital literacy skills. A sample of 151 fifth- and sixth-graders was tested three times at yearly intervals to monitor how their skills to collect, create, transform, and safely use digital information progressed. Results at the group level showed a steady linear increase in all four skills, but individual children tended to alternate substantial growth in one year with minimal progress during the next or vice versa. Children made most progress in their ability to collect information whereas their ability to create information improved the least. Development of most skills was moderately related and independent of gender, grade level, migration background, and improvements in reading comprehension and math. Children's socioeconomic status was weakly associated with the ability to collect and safely use information, but not with the other two digital literacy skills.

1. Introduction

Children begin to use digital technologies at a very early age. Two-year-old toddlers regularly watch films and videos, play games and listen to music on tablet computers (Ólafsson, Livingstone, & Haddon, 2014), and half of the children are able to use tablets autonomously by the time they enter school (Kabali et al., 2015; Mourlam, Strouse, Newland, & Lin, 2019). Young children typically learn to operate these devices by observing family members and through interaction with peers (Kumpulainen & Gillen, 2017). Their repertoire of skills expands further when they start using computers for school work, for example to search for information or create reports and slideshows. Judging by the nature of these activities, school-aged children likely improve both their technical competence and their intellectual capacity to handle digital information. But do they? This question is hard to answer because existing research predominantly targets teenagers and adolescents (Marsh et al., 2017; Ólafsson et al., 2014). The present study aimed to address this paucity of information by examining how children's digital literacy skills develop in the upper-elementary grades.

We use the term 'digital literacy' to refer to the ability to use computers as a receptive and productive tool to collect, create, transform, and safely use information (cf. Fraillon, Schulz, & Ainley, 2013). This ability encompasses the technical skills to use software and operate digital devices as well as the cognitive knowledge and skills to effectively retrieve, evaluate and interact with digital information. As children cannot be expected to make full use of the technological affordances available, we focused our

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longitudinal assessment on the digital literacy practices children engage in on a regular basis for school work. According to national and international benchmarking studies, the most common school-related activities are collecting information online, and creating and editing documents (Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014; Kennisnet, 2017a; Ólafsson et al., 2014). The safe and secure use of online information was added as a fourth aspect because of its societal importance (European Commission, 2018) and presence in several recent projects (e.g., EU Kids Online, ICILS, DigiLitEY). We elaborate the four pillars of our study two by two in the literature review below.

2. Literature review

2.1. Collecting and safely using information

Estimates are that teenagers in Western countries search the Internet at least once a week to collect information for school-related purposes—and probably much more often for private reasons. It is therefore not surprising that most teens (89%) express great confidence in their ability to access and evaluate information online (Fraillon et al., 2014). However, correlations between self-perceived competence and actual performance are moderate in case of technical skills and nonexistent for the advanced cognitive skills because students generally overestimated their own capabilities (Aesaert, Voogt, Kuiper, & Van Braak, 2017; Pora, Blau, & Barak, 2018).

Research specifically targeting children is scarce. Studies conducted around the start of this century found that elementary-school children have a basic command of web browsers and search engines but fall short on the more sophisticated skills such as specifying appropriate keyword terms and evaluating the quality of information and the credibility of its source (see, for an overview, Kuiper, Volman, & Terwel, 2005). Recent case descriptions and training studies suggest that these conclusions still hold today (Aesaert & Van Braak, 2015; Kroustallaki, Kokkinaki, Sideridis, & Simos, 2015; Vanderschantz, Hinze, & Cunningham, 2014), thus leaving ample room for developmental growth.

Developmental growth certainly seems possible in children's understanding of the risks and ethical issues involved in dealing with digital information. Although many parents believe that young children are hardly exposed to online risks, one in eight children actually comes across inappropriate content or has unwanted contact with others online (Chaudron, 2015; Livingstone, Haddon, Görzig, & Ólafsson, 2011). Fewer children are victims of cyberbullying but the impact of receiving such hurtful messages is more severe (Livingstone et al., 2011). The safe and secure use of digital information has nevertheless received remarkably little attention in schools. In the Netherlands, for example, less than 10 percent of the teachers address the topic in their lessons (Kennisnet, 2017b). Despite this ostensible disregard, children somehow manage to advance their understanding of Internet safety as more than half of the 11- to 16-year-olds are able to block unwanted content, change privacy settings, and find safety advice online (Byrne, Kardefelt-Winther, Livingstone, & Stoilova, 2016; Livingstone et al., 2011). The present study sought to reveal how and to what extent this ability emerges in the upper-elementary years.

2.2. Creating and transforming information

The two remaining pillars of our study concern creating and transforming digital information. Consistent with existing frameworks, 'creating information' relates to generating information products from scratch, whereas 'transforming information' refers to changing the way existing information is presented, which typically involves reformatting text (Aesaert, Van Braak, Van Nijlen, & Vanderlinde, 2015; Fraillon et al., 2013; Kennisnet, 2017a). Both activities require basic computer skills, which are generally in place at an early age. Pre-schoolers are able to use the keyboard and mouse by the age of four (Nikolopoulou & Gialamas, 2017) and refine and extend these foundation skills in the lower grades, for instance by interacting with educational software. Sixth-graders are able to perform basic actions such as typing and copying text, and inserting images (Aesaert & Van Braak, 2015) but are generally incognizant of the more advanced formatting options such as changing the line spacing or text wrapping style (Van der Meij, 2012)—which they do master at a later age (Fraillon et al., 2014). This makes reformatting a document an appropriate task for studying the development of children's ability to transform information.

Creating information was examined by having children design a slideshow presentation. This task involved more than producing a series of fancy slides: children had to decide what information content to present, how that information should be structured and written, and how layout and formatting options could be used to get their message across (Fraillon et al., 2013). Children in the upper-elementary grades regularly prepare this kind of slideshows, for example to hold a speech, give a book review, or present the outcomes of a school project (Kennisnet, 2017a) but to our knowledge these practices have not been the subject of scientific investigation. Studies with older students are equally scarce but the ICILS project found that 64 percent of the 14-year-old high school students consider themselves capable of creating multimedia presentations (Fraillon et al., 2014). As data on these students' actual performance unfortunately is lacking, one can only guess how accurate their self-judgements are. In any case, this result gives some indication that children's ability to create slideshow presentations will be less than perfect. Whether and to what extent these skills develop will be investigated in this study.

2.3. Individual differences in digital literacy

The study also examined how digital literacy develops in children with different characteristics. Although individual differences in children's digital literacy are underrepresented in the literature, some useful insights might be gleaned from research with teenagers. These results show that performance in reading comprehension and mathematics is positively associated with proficiency in digital literacy (Hatlevik, Scherer, & Christophersen, 2017; Hua, Gongb, Laib, & Leunga, 2018; Van Deursen & Van Dijk, 2016). A similar consistent positive relationship exists between students' digital literacy and the socioeconomic status (SES) of their homes (Aesaert & Van Braak, 2015; Fraillon et al., 2014; Hatlevik, Ottestad, & Throndsen, 2015; Siddiq, Gochyyev, & Wilson, 2017; Zhong, 2011). The impact of gender is less straightforward. Some studies established that girls are more digitally literate than boys (Aesaert & Van Braak, 2015; Hatlevik et al., 2017; Kim, Kil, & Shin, 2014) whereas other studies found no gender differences (Hatlevik & Christophersen, 2013; Siddiq et al., 2017) or report that boys outperformed girls (Zhong, 2011). Evidence regarding the influence of students' backgrounds is equally inconclusive. Students without migrant backgrounds tended to have higher self-reported digital literacy skills than their peers with a migrant background in some studies (Fraillon et al., 2014; Hatlevik et al., 2015) but other studies found no such effect (Kennisnet, 2017a).

3. Research questions

Based on this snapshot of the research literature, it is probably safe to assume that digital literacy is predominantly investigated in teenagers. Research specifically targeting children is scant and the studies that do exist merely portray children's digital literacy skills at a certain point in time. As observed proficiency levels are rarely compared across age groups and longitudinal assessments are nonexistent, there is a dearth of evidence on how digital literacy develops in children. More research is also needed to identify and explain possible developmental differences. Studies conducted with teenagers found some potentially relevant characteristics that may or may not generalize to the development of digital literacy in children. The present study therefore aimed to find out (1) how digital literacy develops in upper-elementary schoolchildren; (2) whether the skills to collect, create, transform, and safely use digital information develop at similar pace; (3) whether the development of these skills is related; and (4) how this development depends on child characteristics and socio-demographic factors.

4. Method

4.1. Research context and participants

Our sample was drawn from a large public elementary school in the eastern part of the Netherlands. The school, established in 2001, is located in a suburban area with an above-average social status (0.91 on a scale of −7.78 to 2.82; The Netherlands Institute for Social Research, 2019). The school is based in a community center with a library, a daycare center and a gym. The school population well exceeds 600 children divided over 6 units of approximately 100 children. Each unit contains all elementary grade levels (i.e., grades 1–8), with 15–20 children per grade. The teaching staff consists of 45 general teachers, mostly part-timers, and 5 specialist teachers for subjects like advanced math, physical education, music, and science and technology. This staff is supported by teaching assistants and a school pedagogue.

Units have an open workspace architecture with room dividers to separate the lower-, middle- and upper-grades. Along the walls of each unit are 10 Windows computers with Microsoft Office installed (tablet computers entered the school in 2018). Children can use this equipment for their school work at will and their teachers actually encourage them to do so as part of the school's pedagogical mission. Specifically, the school embraces a child-centered approach to education that conveys the competencies of the 21st century. This vision has materialized in practices such as individual weekly study tasks, differentiated instruction, collaborative learning, and authentic forms of assessment. The school offers children ample opportunities to practice and apply their digital literacy skills, but does not provide any formal training in these skills. As such, the school provided an ideal context for studying the natural development of digital literacy.

We started our longitudinal assessment with 182 children: 90 fifth-graders with a mean age of 7.91 years ($SD = 0.63$), and 92 sixth-graders who were one year older on average ($M = 9.03$, $SD = 0.57$). As 31 children left school during the runtime of the project, we report the data of the 151 children who completed all tests. Eighty of them (39 boys and 41 girls) were in fifth grade when their digital literacy was first assessed, the others were in sixth grade (41 boys and 30 girls). Socio-demographic characteristics of this final sample, taken from the school's administration, indicated that most children (85%) originated from Dutch families; the remaining 27 children (15%) came from parents born in a variety of mostly non-western countries. Children's SES was inferred from their parents' highest level of education attained. The majority of our sample (72%) came from high-SES homes; the rest came from families with either a middle (21%) or low SES (7%).

4.2. Materials

4.2.1. Internet test

A 16-item paper-and-pencil test tapped children's ability to collect and safely use online information. A written item format was preferred to practical Internet search tasks because it provides uniform testing conditions in successive years. Children's ability to collect information was assessed by 13 items that revolved around the search for and evaluation of online information. These items addressed the skills involved in operating browsers and search engines, using keywords and queries, and evaluating information displayed in hit lists and on web pages. Three additional items measured children's understanding of the safe and secure use of online information. These items dealt with popups, phishing messages and Internet ethics, respectively. All 16 items contained a screen capture (e.g., a Google results page) and a question (e.g., which website would you visit first?) children could answer by circling or writing down information in the screen capture. Children's answers were evaluated against a rubric that defined what counted as a correct response; answers that satisfied these criteria were awarded 1 point.

Children took this test three times at yearly intervals. To minimize possible history and content effects, we developed three parallel versions of the test, each designed around a different topic (i.e., thunder, hurricanes, earthquakes). An initial pilot test with 21 children indicated that these versions had a comparable level of difficulty as well as a high interrater reliability (Cohen's $\kappa = 0.94$). A second pilot study with 43 children further showed that the test had sufficient internal consistency (Cronbach's $\alpha = 0.73$), and that item scores correlated with performance on practical search tasks tapping the same skills, $r = 0.56$, $p < .001$.

4.2.2. Word assignment

The ability to transform information was assessed by having children modify the styling of a text document. Children performed this assignment on a Windows desktop computer with Microsoft Word. On their screen was a short kids magazine article containing a title, a lead, two subheadings, three paragraphs of text and one image. Children had to reformat this document by changing the visual appearance of designated parts of the article. Requested changes concerned the font size, font style, font color, left margin, first line indent, line spacing, and text wrapping style. All modifications were indicated on a printed handout, along with a visualization of the desired end result. As with the Internet test, we prepared three versions of the text that merely differed with regard to content; the structural features of the text and their reformatting were identical across versions.

The development of this assignment included pilot-tests with three children whose comments and performance helped improve the handout. The final version of the assignment was tried out with 81 children. Two independent raters scored their formatting changes as either successful (1 point) or unsuccessful (0 points), and agreed in 97 percent of the cases (Cohen's $\kappa = 0.94$). Internal consistency of the seven reformatting tasks was satisfactory (Cronbach's $\alpha = 0.73$).

4.2.3. PowerPoint assignment

Children's proficiency in creating information was examined by having them prepare a slideshow presentation with Microsoft PowerPoint. A flyer explained the purpose of the presentation (to enter a contest) and gave some general suggestions about its content (e.g., introduce yourself, give examples) and styling (e.g., use pictures and slide animations). Children could design whatever kind of slideshow they wished and were allowed to enrich it with visual materials from the Internet. The three versions of this assignment differed only with regard to information content: children had to create a slideshow for a contest to select either the best Dutch school, the best kids book, or children's favorite dish.

The quality of children's slideshows was assessed on three dimensions containing three aspects each. The first dimension, technical quality, concerned the formatting of both text and pictures as well as the use of animations or slide transitions. Graphical quality involved the esthetic properties of the slideshow as a whole, the layout of individual slides, and the styling of slide elements. Quality of content was determined by the amount of topical information given, how this information content was structured, and how it was phrased. Children could earn up to three points for each aspect and, hence, a maximum score of 9 points per dimension. Total scores could thus range from 0 to 27 points.

Psychometric properties were determined from data of the 81 children who also participated in the Word assignment tryout. As we had no specific hypotheses about the three quality dimensions, total scores were used in these and subsequent analyses. Interrater reliability was assessed three times with different raters; results showed an increase in agreement (Cohen's κ) from 0.65 through 0.69 to 0.85. The Cronbach's α index of internal consistency was 0.62.

4.2.4. Reading comprehension test

Children's reading comprehension was assessed by a standardized progress-monitoring test developed by the Dutch Institute for Educational Measurement and approved by the Ministry of Education. The test comprised 50 multiple-choice items that tapped children's ability to understand the meaning of different types of texts. Test content was adapted to children's development in reading comprehension such that a more difficult version of the test was administered each year. Children's answers were transformed into an ability score that enabled valid comparison over time and across age groups. This ability score was used in the analyses reported here.

4.2.5. Math test

Children's mathematical skillfulness was assessed by a governmentally approved progress-monitoring test (De Vos, 2006) that required children to add, subtract, multiply or divide one and two-digit numbers (e.g., $17 + 4$; $24 \div 2$). The test contained 200 items of increasing difficulty; children had to complete as many items as they could within 5 min. Their test scores represent the number of correctly solved items.

4.3. Procedure

Information regarding children's socio-demographic characteristics (i.e., age, gender, grade, migration background, and parental education) was obtained from the school administration. All tests and assignments were administered in the first quarter of 2016, 2017 and 2018. Children received the three versions of each digital literacy test in random order across these years, with a 12-month interval between test administrations. The Internet test was administered to the whole class. Following a short standardized instruction, children completed the test without time limit in approximately 20 min. The Word and PowerPoint assignments were administered some days later in small groups. Children were first explained the purpose of these assignments and then received the handout for the Word assignment, which they performed individually behind their computer in 10 min maximum. After a short introduction to the PowerPoint assignment, they returned to their computers to create their slideshows during the remaining 20 min. The reading comprehension test and math test, which were part of the school's progress monitoring policy, were administered by the children's regular classroom teachers according to the instructions provided by the test publisher.

5. Results

Table 1 displays children's achievement on the digital literacy tests; mean scores were converted into percentages to ease comparisons among tests. Visual inspection of these scores indicates a steady linear progression in achievement on each test, with marginal differences between grade levels. Mixed-design MANOVA confirmed that children's scores increased significantly over time, $F(8, 142) = 75.46$, $p < .001$, $\eta_p^2 = 0.81$. The nonsignificant time × grade interaction further indicates that this improvement was independent of grade level, $F(8, 142) = 1.21$, $p = .299$, $\eta_p^2 = 0.06$. The between-subject factor 'grade level' had no effect, $F(4, 146) = 0.48$, $p = .747$, $\eta_p^2 = 0.01$, which means that, overall, fifth-graders scored on par with the sixth-graders. Follow-up univariate ANOVAs evidenced that the observed increase in scores applied to all four digital literacy skills, $F(2, 298) > 31.72$, $p < .001$, $\eta_p^2 > 0.18$. Planned contrasts using the polynomial method indicated that children's performance on each test increased linearly over time, $F(1, 150) > 58.73$, $p < .001$, $\eta_p^2 > 0.28$, and did not level off, $F(1, 150) < 0.34$, $p > .560$, $\eta_p^2 < 0.002$.

To determine whether the four digital literacy skills develop at similar rate, we first calculated gain scores for each test by subtracting children's initial score from their final score. As the tests had a different maximum number of points, all gain scores were standardized by dividing the observed growth by the maximum possible growth. In formula: $score_{2018} – score_{2016} ÷ (maximum score – score_{2016})$. These standardized gain scores are reported in Table 2 and were analyzed by within-subject ANOVA; grade level was dropped from this and subsequent analyses because it had no effect on the development of digital literacy. The ANOVA[1] returned a significant difference in the extent to which children improved in the four digital literacy skills, $F(1.92, 285.75) = 21.16$, $p < .001$, $\eta_p^2 = 0.12$. Post-hoc comparisons with Bonferroni correction showed that the ability to collect information increased more than the three other skills, *p's* < 0.001. Safely using information increased as much as transforming information, $p = .535$, and creating information, $p = 1.000$, whereas transforming information increased more than creating information, $p < .016$.

In addition to analyzing the relative pace of development, we examined whether the development of the four digital literacy skills was related. The correlations in Table 2 show that this was indeed the case. Specifically, improvements in collecting information were related to improvements in the three other digital literacy skills. Advancements in the ability to transform and safely use information were weakly related, and independent of improvements in creating information. We also correlated the standardized gain scores in adjacent years for each skill. The outcomes are displayed in the diagonal cells of Table 2, and show a significant negative association between the growth in both time periods for all skills except collecting information. This means that the observed linear increase in scores did not always apply to all children in our sample. Rather, children who made considerable progress in the first year tended to improve moderately or not at all over the second year and vice versa.

Of final interest was whether and how the development of digital literacy was contingent on children's socio-demographic characteristics and their improvements in reading comprehension and math. Between-subject MANOVA's on the standardized gain scores depicted in Table 3 showed that boys improved their digital literacy skills as much as girls did, $F(4, 146) = 2.24$, $p = .068$, $\eta_p^2 = 0.06$. Children's background did not impact the development of digital literacy either, $F(4, 146) = 1.18$, $p = .324$, $\eta_p^2 = 0.03$, meaning that children from Dutch families made similar progress as their peers with a migration background. Possible differences due to children's SES were analyzed by nonparametric correlations instead of MANOVA because homogeneity of variance could not be assumed and the SES-levels contained an unequal number of children. Table 4 shows that SES was weakly associated with improvements in the ability to collect and safely use information: children from higher SES families tended to improve more in these skills than children from families with a lower SES. Progress in the other two digital literacy skills was independent of SES. The correlations in Table 4 further show that children's improvements in all four digital literacy skills were independent of their improvements in reading comprehension and math.

6. Discussion

Today's children grow up in a technologized world. Their access to and use of digital devices and applications has been scarcely documented while even less is known about how children develop to become digitally literate. This study showed that, without formal training, the average level of children's digital literacy skills improves steadily throughout the upper-elementary years. The overall increase in test scores ranged between 19 and 44 percent, albeit with considerable individual variation. What exactly these improvement rates mean is hard to tell in absence of any benchmark scores; follow-up studies using similar tests and assignments are needed to put the present findings in perspective. Future research should also examine whether the observed natural pace of development can be accelerated through designated training of digital literacy skills, in addition to offering frequent practice opportunities. Results of long-term training studies suggest that this will be case (e.g., Kroustallaki et al., 2015).

Results regarding our second research question show that the four digital literacy skills measured in this study do not develop at similar pace. Children's proficiency in collecting information improved nearly twice as much as the other three skills. This

[1] As the sphericity assumption was violated, $\chi^2(5) = 120.78$, $p < .001$, the Greenhouse-Geisser *F*-ratio is reported; this is reflected by the decimal value for the degrees of freedom.

Table 1
Annual performance in digital literacy by grade.

Digital literacy skill	2016		2017		2018	
	M	*SD*	*M*	*SD*	*M*	*SD*
Collecting information						
Grade 5[a]	49.16	15.20	59.86	14.79	71.37	16.40
Grade 6[b]	46.70	16.54	61.30	15.59	73.65	13.34
Safely using information						
Grade 5	39.17	24.71	44.79	23.40	53.75	23.27
Grade 6	32.39	26.64	47.07	26.17	55.99	22.41
Transforming information						
Grade 5	28.75	16.15	37.86	16.72	48.93	18.29
Grade 6	30.38	16.36	42.25	21.79	51.91	19.95
Creating information						
Grade 5	28.33	10.39	34.07	9.60	42.78	10.46
Grade 6	26.55	10.13	35.89	8.71	43.71	8.62

Note. Scores are percentages of the maximum possible points on each test.
[a] $n = 80$.
[b] $n = 71$.

Table 2
Correlations, means and standard deviations of standardized gain scores (2016–2018).

	1	2	3	4	*M*	*SD*
1. Collecting information	.04				43.98	39.53
2. Safely using information	.39**	−.33**			18.78	59.20
3. Transforming information	.19*	.22**	−.44**		28.57	28.14
4. Creating information	.17*	.07	.09	−.42**	20.56	15.56

Note. Correlations in the diagonal cells represent the association between the standardized gains in adjacent years for that particular skill.
$^{**}p < .01$ (two-tailed) $^{*}p < .05$ (two-tailed).

Table 3
Standardized gain scores by gender and background.

	n	Collecting information		Safely using information		Transforming information		Creating information	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Gender									
Boys	80	38.89	46.47	21.92	51.90	29.74	27.78	18.12	14.16
Girls	71	49.72	29.14	15.25	66.67	27.24	28.68	23.30	16.18
Background									
Dutch	128	44.10	41.13	18.32	59.72	26.82	28.23	19.91	16.02
Migration	23	43.34	28.61	21.33	56.49	38.29	26.09	24.14	12.39

Table 4
Correlations between standardized gain scores and children's characteristics.

	Collecting information	Safely using information	Transforming information	Creating information
SES[a]	.21*	.16*	.07	.04
Standardized reading gains	.13	−.08	.03	.13
Standardized math gains	.10	.07	−.05	.05

$^{*}p < .05$ (two-tailed).
[a] Spearman's rho.

asynchronous development is presumably due to the pervasive use of the Internet, both in school and at home (e.g., Kennisnet, 2017a; OECD, 2015). Children improved the least in their ability to create information, and the amount of practice could again be the reason why. Although children frequently watch slideshow presentations in school, they less often prepare one themselves. Frequency estimates based on the responses of teenagers point to an occurrence rate of less than once a month in 55 percent of the classrooms (Fraillon et al., 2014; Kennisnet, 2017a). Another reason could be that the PowerPoint assignment was the most open-ended task: children had to create their presentations from scratch, armed with just a few general directions. Such a design challenge is more complicated than the constrained tasks used to measure the other skills. A related explanation is that children's slideshows were also scored on information quality and graphical quality, which require higher-order ICT-competences that are difficult to master at a young age (Aesaert & Van Braak, 2015).

Our results further show that the development of the four digital literacy skills tends to go hand in hand. However, as most overall gains scores were only weakly correlated, we conclude that there is some coherence in children's advancement in using computers as a receptive and productive tool, but also some variation in the extent to which the underlying skills develop. This conclusion does not apply to the ability to create information: this skill improved independent of the other skills, probably for the reasons outlined above. Individual variation was also observed in the annual progress of distinct skills. The negative correlations imply that most skills improve by leaps and bounds, with substantial growth in one year and minimal progress in the next or vice versa. This result refines our initial conclusion that digital literacy skills improve linearly throughout the upper-elementary years. Although this statement is valid at the group level, individual children within that group undergo a more erratic development.

There was also substantial inter-individual variation in children's development of digital literacy. The improvement of some skills was associated with children's SES, which is consistent with the outcomes of studies targeting teenagers (e.g., Aesaert & Van Braak, 2015; Hatlevik et al., 2015; Siddiq et al., 2017). This effect is probably due to the higher level of parental mediation in higher-SES families (Kennisnet, 2017a; Kumpulainen & Gillen, 2017), in particular because positive relations were found for skills associated with using the Internet, which is a common digital activity at home. Gender and migration background were unrelated to children's developments in digital literacy. These results contradict the evidence of some cited studies conducted with high school students, and suggests that not all findings obtained with teenagers apply to children. A second explanation is that factors known to affect the *performance* of a particular skill do not necessarily impact the *development* of that skill. Both possibilities imply that caution is in order when generalizing the conclusions from benchmarking studies conducted with teenagers to developments in children, and underscore the importance of more research into the development of digital literacy in children (Marsh et al., 2017; Ólafsson et al., 2014).

Advancement in digital literacy was independent of children's age, and the same goes for their annual performance scores. This ostensibly counterintuitive result could be due to the fact that the sixth-graders were only one year older than the fifth-graders, which might be too little for age-related differences to show (see, for similar findings, Kruit, Oostdam, Van den Berg, & Schuitema, 2018). Finally, although previous research established positive relations between performance in reading comprehension, mathematics, and digital literacy (Hatlevik et al., 2017; Hua et al., 2018; Van Deursen & Van Dijk, 2016), this study shows that these skills develop independently. This result substantiates the above conclusion that performance and development are separate constructs and should be treated as such in research and practice. Teachers, for example, should bear in mind that children who develop well in reading and math are not necessarily the ones that make most progress in digital literacy.

A similar practical implication relates to the asynchronous and erratic development of digital literacy. Children who are ahead of their class in, for example, searching the Internet can be mediocre in editing Word documents or creating PowerPoint presentations, and their improvement in these skills cannot be predicted from their actual performance level. Teachers should therefore keep a close watch on the development of distinct skills in individual children, and remediate possible deficiencies on an as-needed basis. Such careful monitoring is also needed because neither general learner characteristics nor improvements in reading comprehension and math predict the development of digital literacy.

Like any scientific investigation, this study has some limitations. The first one is that the developmental trajectories revealed in this study may not apply to children from schools that offer ICT-training as part of their regular curriculum. Other restrictions relate to the somewhat skewed distribution of SES and migration background, meaning that relatively many children in our sample originated from Dutch families with a high SES. In a more balanced sample, both socio-demographic factors might have a more determinant influence on the development of digital literacy. Finally, this study did not address children's use of digital technologies at home. We initially felt that the costs of validly collecting these data would outweigh the benefits—that is, more home use is obviously associated with higher performance in school. In hindsight, we regret this decision because children's digital practices at home could have yielded additional insight in the observed developmental differences.

7. Conclusion

This study is an important first step to understand how digital literacy emerges in elementary schoolchildren. The longitudinal results show that the natural development of digital literacy skills is slow and often susceptible to growth spurts. Progress is most pronounced in children's ability to collect information on the Internet, whereas their ability to create digital information products from scratch improves the least. Developmental growth of most skills is moderately related, largely unaffected by children's socio-demographic characteristics, and independent of their achievement gains in the core subjects of reading and math.

Declarations of interest

None.

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