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The Early Roots of the Digital Divide:

Socioeconomic Inequality in Children's ICT Literacy from Primary to Secondary Schooling

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The Early Roots of the Digital Divide:
Socioeconomic Inequality in Children's ICT Literacy from Primary to Secondary Schooling

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Abstract

Information and communications technology (ICT) skills are crucial for labour market success and full participation in society. Socioeconomic status (SES) inequality in the development of ICT skills would prevent disadvantaged children from reaping the benefits of the digital age. Besides, the digital divide in ICT literacy might add to the already well-documented large and persistent SES inequality in 'hard' skills—like math, reading, and science. This article studies the roots, evolution, and drivers of SES inequality in ICT literacy from age 8 to 15 in Germany. Drawing from the German *National Educational Panel Study* (NEPS), we highlight five main findings: (1) SES gaps in ICT literacy exist as early as age 8 (grade 3) and are similar in size compared to SES gaps in hard skills; (2) like hard skills, SES gaps in ICT literacy remain stable over primary and tracked lower secondary schooling; (3) ICT access and use at home and school do not substantially explain SES gaps in ICT literacy at any age; (4) selection into school tracks seems a critical pathway, although not necessarily a casual one, leading to SES inequality in secondary school; (5) SES gaps in ICT literacy are not observed among children with similar levels of hard skills. We discuss the implications of these findings for the interdisciplinary literature on social stratification, skill formation, and the digital divide.

Keywords: digital skills, ICT literacy, socioeconomic status inequality, educational inequality, digital divide, Germany

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Related publications and reports:

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Contents

1 Introduction

The ubiquity of digital technologies profoundly affects how we find, process, and evaluate information in contemporary societies. Successfully navigating the vast fluxes of online information, beyond mastering digital devices, is essential for raising integrated and informed citizens. The new set of skills necessary to the master and benefit from recent technological innovations received different names, ranging from digital competencies, information and communications technology (ICT) literacy, to 21st Century skills (Fraillon et al., 2019; van Laar et al., 2017; Carretero, Vuorikari & Punie, 2017; Educational Testing Service [ETS], 2002).[1]

Digital competencies are also crucial for labour market success. Post-industrial economies experienced a hardwired workplace digitalisation driven by the fast-paced outbreak of personal computers and digital devices (Bisello et al., 2019), the Internet, robotics, and artificial intelligence (Fernández-Macías & Bisello, 2021). Jobs in Science, Technology, Engineering and Mathematics (STEM), which require high levels of analytic and digital skills, are among the most rewarding and complementary to technological change (Liu & Grusky, 2013) and account for the lion's share of productivity and employment growth in many countries.

Nowadays, most jobs require at least basic digital competencies (González Vázquez et al., 2019) due to technological change and occupational upgrading (Oesch & Piccitto, 2019). However, the increasing demand for ICT skills in the digital age coincides with a shortage of workers (existing and prospective) mastering such skills (European Commission, 2021; Carretero, Vuorikari & Punie, 2017). Besides, those jobs with the largest share of routinary tasks, which involve less analytical and ICT skills, are at the highest risk of automation and redundancy (Acemoglu and Restrepo, 2021).

For all these reasons, international institutions (OECD, 2019a; Conrads et al., 2017)[2] and national governments agree (ACARA, 2018) on the strategic importance of incorporating ICT competencies transversally in educational systems' curricula as early as possible as to prepare students (and teachers) for full participation in digital societies. The COVID-19 pandemic has sped up this unfolding digital transition by highlighting the importance of students' and parents' ICT literacy to fight educational inequalities in the context of school closures and home-schooling (Engzell, Frey & Verhagen, 2021).

The existing research highlighted three dimensions of the digital divide: ICT access, ICT usage, and ICT literacy (Scheerder, van Deursen & van Dijk, 2017). The widespread availability of Internet connection and portable devices from the late 2000s shifted the focus from discussing inequality in access to inequality in usage and literacy (OECD, 2015; van Deursen & van Dijk, 2014). High SES students tend to use ICT for educational purposes (van Dijk, 2012) (i.e., doing homework; retrieving information; reading news) more than their less-advantaged schoolmates. Mechanisms underlying this relationship are parental cultural resources and ICT skills (Becker, 2021; Gracia et al., 2020; Notten & Becker, 2017).

ICT access and ICT use do not automatically guarantee that young generations develop advanced digital skills, however. According to the *International Computer and Information Literacy Study* (ICILS) (Fraillon et al., 2018), over one-third of the students aged 15 lack basic digital competencies in 9 out of 14 European Union countries. What is more, the family background explains students' proficiency in ICT skills (Fraillon et al., 2018; 2019; Scherer & Siddiq, 2019). SES inequality in ICT literacy may be particularly relevant to social mobility. SES

[1] We use the terms 'ICT literacy' and 'digital literacy' (or skills/competencies) interchangeably in this article (for details on different definitions see Rodrigues, Fernández-Macías & Sostero, 2021).

[2] 21st Century skills movement; European Commission's Digital Education Action Plan 2021-2024; European Digital Competence Frameworks for Citizens and Educators (Carretero, Vuorikari & Punie, 2017; Redecker, 2017); PISA-2021 ICT framework (OECD, 2019b).

gaps in 'hard' skills—like mathematics, science and reading—are well-documented already from preschool age in many countries in- and outside Europe (Bradbury et al., 2015; Feinstein; 2003; von Hippel & Hamrock, 2019; Passaretta, Skopek, & van Huizen 2022; Skopek & Passaretta, 2021). These early gaps remain rather constant over schooling and account for a big chunk of the intergenerational transmission of educational and occupational attainment (Jackson, 2013; Barone & Werfhorst, 2011; Kerckhoff, Raudenbush & Glennie, 2001). An additional social divide in the development of digital skills would prevent disadvantaged students from fully reaping the benefits of the digital age and even exacerbate the intergenerational transmission of social disadvantage.

2 Research questions and contribution

Notwithstanding the relevance of ICT literacy for social mobility in the digital age, we know little about SES gaps in ICT literacy compared to traditional academic domains (Scherer & Siddiq, 2019). Moreover, while SES gaps in ICT skills among adolescents (Fraillon et al., 2019; Aesaert & van Braak, 2015) and adults (OECD, 2019a) are well documented, we know little about when these gaps emerge first and how they evolve in childhood (Lazonder et al., 2020). And yet research focused on family- and school-level mechanisms underlying social inequality in ICT literacy is scant.

This article deepens on the roots, the evolution, and the drivers of SES inequality in ICT literacy[3] among children and pre-adolescents in one of the largest democracies in Europe, that is Germany. We complement the existing literature by addressing the following research questions:

(1) When does SES inequality in ICT literacy emerge and how does it evolve over primary and lower secondary schooling?

(2) Which family (i.e., ICT access and usage patterns) and school characteristics (i.e., tracking, ICT facilities) explain SES inequalities in ICT at various points of children's life course?

Drawing data from the German *National Educational Panel Study* (NEPS) (Blossfeld, Roßbach & von Maurice, 2011), we follow-up two cohorts of elementary and lower secondary students from age 7 (grade 3) to age 16 (grade 9). The NEPS implemented a consistent strategy using the *Test of Technological and Information Literacy* (TILT) (Senkbeil, Ihme and Wittwer, 2013). TILT is a reliable and validated instrument to measure ICT meta-competencies beyond technical mastery of devices (i.e., declarative and procedural knowledge of hardware and software) (Senkbeil, Ihme & Wittwer, 2013). Hence, TILT measures skills that will not become obsolete despite the future technological change. The use of a reliable and consistent instrument is a major advantage over most of the previous research, which often used inconsistent ICT measures and definitions (Siddiq et al., 2016).

The measurement of ICT skills remains a controversial field, however (Siddiq et al., 2016). ICT literacy involves cross-domain skills like problem-solving, critical thinking, and metacognition

[3] Main definitions of ICT: (a) International Computer and Information Literacy Study - "Individual's ability to use computers to investigate, create, and communicate in order to participate effectively at home, at school, in the workplace, and in society" (Fraillon, Schulz, & Ainley, 2013:17); (b) Educational Testing Service – "ICT literacy is the interest, attitude and ability of individuals to appropriately use digital technology and communication tools to access, manage, integrate and evaluate information, construct new knowledge, and communicate with others in order to participate effectively in society" (ETS, 2002:2); (c) Digital Competence Framework for Citizens (DIGCOMP) – five competence areas including "(1) Information and data literacy (e.g., Evaluating data, information, and digital content); (2) Communication and collaboration (e.g., interacting and sharing through digital technologies); (3) Digital content creation (e.g., developing digital content and programming); (4) Safety (e.g., protecting devices, personal data, privacy, health, well-being, and the environment); (5) Problem solving (e.g., solving technical problems, creatively using digital technologies)" (Carretero, Vuorikari, & Punie, 2017).

in accessing, managing, integrating, evaluating, and creating digital information (Gnambs, 2021; ETS, 2002). Although these ICT skills positively correlate with traditional hard skills, like general cognitive ability and domain-specific competencies, ICT literacy is widely considered a unidimensional construct (Hatlevik, Scherer, & Christophersen, 2017; Siddiq et al., 2016; Senkbeil et al., 2013). Against this background, one interesting question is how SES inequality in ICT literacy ranks and evolves compared to SES gaps in core competencies, such as reading, math, and science. Relatedly, it is also interesting to understand whether SES gaps in ICT literacy are just by-products of SES inequalities in parenting and school environments shaping hard skills (i.e., through cross-fertilisation). To the best of our knowledge, no studies have tried to find answers to these questions in a unified research design. This article contributes to filling these gaps by asking:

(3) How does SES inequality in ICT benchmark with inequalities in other traditional competence domains (hard skills)?

(4) Are there SES gaps in ICT literacy among children with similar proficiency levels in the traditional competence domains (hard skills)?

3 Theory and context

3.1 Parents, schools, and social inequality in ICT literacy

Extensive research from the sociology of education, the economics of education, and developmental psychology has documented how cultural, economic, and social resources in the family shape children's skill development early in life through monetary investments and parenting practices (Francesconi & Heckman, 2016; Duncan & Magnuson, 2011; Farkas, 2003; Bourdieu, 1986).

Cultural reproduction theories highlight how families' unequal stock and transmission of cultural capital explain SES inequality in academic achievement (Bourdieu & Passeron, 1990). The previous research has examined the following dimensions in the transmission of cultural capital between parents and children: reading habits (i.e., bedtime stories), educational material resources (i.e., books, educative games, computers), cultural communication (i.e., teaching them to be analytical, to reason, and to be argumentative), and extracurricular activities (Jaeger & Breen, 2016). Furthermore, parents with high cultural capital tend to follow an educational strategy of "concerted cultivation" for their children (i.e., structured activities, supervision of homework) (Lareau, 2003), while working-class parents are more likely to follow a "natural growth" strategy, which generally involves less supervision and organised time (Bodovski & Farkas, 2008).

This framework was also applied to the case of SES inequality in ICT access, use and literacy through the concept of digital capital (Drabowicz, 2017; Ignatow & Robinson, 2017). Digital capital is '"a set of internalised abilities and aptitudes" (digital competencies) as well as "externalised resources" (digital technology) that can be historically accumulated and transferred from one arena to another' (Ragnedda, Ruiu & Addeo, 2020, pp. 793-794). High-SES parents, having high cultural and digital capital, use ICT more for informational purposes than low-SES parents (van Deursen & van Dijk, 2014) and can maximise their children's learning opportunities arising from the use of technology.

High-SES families tend to monitor their children's amount and type of use of digital devices by setting time rules and encouraging educational activities (i.e., using computers for doing homework and learning; retrieving information; reading news; emailing) (Nikken & Opree, 2018; Notten & Becker, 2017; OECD, 2015; Chaudron, 2015; Livingstone et al., 2015). Overall, these parental practices related to different patterns of ICT usage by family SES are similar to those explaining SES gaps in time use and educational achievement (Gracia et al., 2020; Cano, Perales & Baxter, 2019). Altogether, family resources and parenting strategies may foster educationally oriented ICT use and children's ICT literacy in the same way they intensively nurture the development of hard skills like vocabulary, reading, and numeracy skills (Fernald, Marchman & Weisleder, 2013; Lugo-Gil & Tamis-LeMonda 2008; Farkas, 2003).

Although ICT is not a specific subject in many education systems, school learning environments may also shape SES inequality in ICT literacy. Schools' differences in average students' ability and SES composition (Robinson, Wiborg & Schulz, 2018) and ICT infrastructures and staff training (European Commission, 2013, 2019; Gerick, 2018; Redecker, 2017) might account for a substantial share of SES gaps in ICT literacy. For instance, those schools equipped with modern devices with Internet connection in the classroom, disposing of principals and teachers trained in digital teaching/learning methods (Borgonovi & Pokropek, 2021), or even offering extracurriculars on coding and robotics might considerably boost students' ICT literacy (Gerick, Eickelmann, & Bos, 2017) and the SES inequality therein. In the specific case of Germany, Gerick et al. (2017) found a positive association between teachers' use of ICT in schools and students' ICT literacy.

3.2 The German context

Germany employs the largest amount of ICT specialists in the EU (European Commission, 2021). Besides, only 27.3 % of German students in grade 8 (age 14) lack basic ICT skills, which is a relatively low level when compared with countries such as Italy (62.7%) or Luxembourg (50.6%) (Fraillon et al., 2018). Nevertheless, the German educational system displays high levels of SES inequality in ICT literacy (Fraillon et al., 2019) and other competence domains (OECD, 2018) when looking at adolescents. Adolescence may represent the end of a process starting long before, however. How do SES gaps in ICT literacy evolve as children navigate primary and lower secondary schooling? Germany represents an interesting theoretical case to examine this question as the German education system is often described as a formidable sorting machine.

Germany applies early school tracking at age 10–12 (after grade 4 or 6, respectively). Children are tracked into academic or vocational pathways leading to very different educational certificates and occupational opportunities. Some federal states enforce binding recommendations linked to students' ability for tracking (Buchholz et al., 2016). Hence, some authors argue that early school tracking functions as a bottleneck that reinforces early SES gaps in skills and contributes to low educational mobility levels (OECD, 2018; Bol & van de Werfhorst, 2013). Notwithstanding the potential dis-equalising role of tracking, SES gaps emerge long before school entry and remain stable even after tracking (Skopek & Passaretta, 2021). This article contributes to this debate by analysing the evolution of SES gaps in ICT skills compared to hard skills before and after school tracking in the primary-to-secondary education transition.

4 Data, variables, and methods

4.1 Data

We use information from the *Kindergarten cohort* (Starting Cohort 2 or SC2 henceforth) and the *Grade 5 cohort* (Starting Cohort 3 or SC3 henceforth) of the *German National Educational Panel Study* (NEPS) (Blossfeld et al., 2011).[4] SC2 and SC3 sampled schools in the first stage

[4] This inquiry uses data from the NEPS: Starting Cohort Kindergarten, 10.5157/NEPS:SC2:8.0.0. From 2008 to 2013, NEPS data were collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS is carried out by the Leibniz Institute for Educational Trajectories (LIfBi) at the University of Bamberg in cooperation with a nationwide network.

and students in the second stage. SC2 comprises a representative sample of children attending the first year of kindergarten in 2010/2011 (N = 2,996) and followed up to grade 4. SC3 includes a representative sample of children attending grade 5 in 2010/2011 (N = 6,112) and followed up to grade 9. Both cohort samples were supplemented by refreshment samples in Wave 3, which represents grade 1 for SC2 (N = 6,341) and grade 7 for SC3 (N = 2,205). Overall, these samples are representative of German schools and students.

We employ data from nine waves overall: three (Waves 4–6) from SC2 and six (Waves 1–6) from SC3. The nine waves cover a period ranging from grade 2 to 9 (age 7–16 approximately). Children were tested in a variety of competence domains in each wave. Nevertheless, the number and type of tested domains varied across waves (even within the same cohort). ICT literacy was tested three times over the observation window: grade 3 in SC2 (age 8 approximately) and grades 6 and 9 in SC3 (age 12 and 15 approximately). Testing in other domains (math, science, and reading) did not perfectly coincide with ICT literacy but took place in a similar time frame.[5] Table 1 provides details on the timing of testing for each of the competence domains.

The data do not allow us to follow the same children throughout the whole period from grade 2 to 9, but the cohort-sequences design of the NEPS allows an approximation based on cohort comparisons and comparable measures. Therefore, our comparison hinges on two cohorts and their respective refreshment samples. Longitudinal attrition rates were generally low but occurred in both cohort samples (Zinn et al., 2018). The school-based sampling design resulted in substantial (but not selective) attrition at the transition from kindergarten to first grade (Wave 2-to-3 in SC2). We used the design weights and the longitudinal weights provided by the NEPS to account for disproportions in the initial samples and potential attrition over waves.

The analytical samples for the description of the evolution of SES inequality in achievement change for each domain and wave as we aim at maximising sample size. We draw on smaller subsamples when assessing the drivers of SES gaps in ICT literacy and the residual SES gaps (when comparing equally-achieving students in hard skills) to accommodate listwise deletion on key mediators and test scores. Overall, depending on the analyses, our samples range from 3,473 to 5,102 students in SC2 and from 1,576 to 3,462 students in SC3. Table A2 in the Appendix shows that the magnitude of SES gaps in ICT literacy in the overall samples and the restricted subsamples are virtually identical.

4.2 Variables

ICT Literacy. ICT literacy is a meta-competence measured with a paper-and-pencil test (31-36 items with multiple-choice responses) and designed explicitly by the NEPS: the *Test of Technological and Information Literacy* (TILT) (Senkbeil et al., 2013). TILT embraced the ETS (2002) definition of ICT literacy (see footnote 3), conceptualised as a unidimensional construct comprising the facets of process components and software applications. Computer literacy's process components[6] represent cognitive and technological aspects of the knowledge and skills needed for a problem-oriented use of modern information and communication technology. The

[5] One of our aims was to compare the evolution of SES inequality in ICT literacy vis-à-vis other domains (math, science, reading) over primary and lower secondary education. To this aim, we extended the overall observation window by +/– 1 wave maximum compared to the observation window for ICT literacy (grades 3–9, age 8–15).

[6] "(1) *Access*: knowledge of basic operations used to retrieve information (e.g., entering a search term in an internet browser, opening and saving a document); (2) *Create*: the ability to create and edit documents and files (e.g., setting up tables, creating formulas); (3) *Manage*: the ability to find information within a program (e.g., retrieving information from tables, processing the hits returned by a search engine); (4) *Evaluate*: the ability to assess information and to use it as the basis for informed decisions (e.g., assessing the credibility of the information retrieved) (Senkbeil et al., 2013)."

facet of software comprises applications[7] used to locate, process, present, and communicate information. Apart from a few items asking for factual knowledge, most items ask students to accomplish computer-based tasks with realistic problems. TILT shows good internal reliability ($\alpha \approx 0.8$) and longitudinal invariance. The test is scaled using Item Response Theory to link the scores across waves and even allow for longitudinal mean-level comparisons in absolute terms (Senkbeil & Ihme, 2017; Senkbeil, Ihme & Adrian, 2014). Table 1 provides details on the timing of measurement of ICT and all variables used in the analyses.

Other domain-specific competencies. Domain-specific competencies come from low-stakes tests (test scores) on mathematics (24 items), reading (33 items) and scientific literacy (26 items). These tests are scaled with Item Response Theory and follow a similar methodology compared to large-scale international assessment studies (e.g., PISA) (Pohl & Carstensen, 2013; Weinert et al., 2011). Test scores in math, science, and reading, likewise ICT literacy, are provided by NEPS as weighted maximum likelihood estimates (WLEs) representing best estimates of children's ability.

Skill stratification. Following the literature on inequality in tests scores, we standardise competence scores within waves to have a mean of 0 and a unit standard deviation in each wave (Passaretta et al., 2022; Bradbury et al., 2015; Reardon, 2011). Hence, we focus on SES inequality in relative terms, that is by comparing the average relative position of children from different SES backgrounds in the distribution of achievements. In this framework, the longitudinal comparison informs us about changes in SES-inequality's relative and not absolute (proficiency) amount. The grade-based design of the NEPS resulted in age variations among children taking a competence test in a particular wave. Part of this variation is substantively related to SES, for example, in the case of grade repetition; part is likely due to sampling error. We removed such non-SES-related differences in the age test before standardisation via residualisation of test scores on a cubic function of exact age at test in each wave. Details on the residualisation procedure can be found in Skopek & Passaretta (2021).

Parental SES. We use the highest years of parental education in the first wave of participation as the primary indicator for family SES. Although not covering all facets of socioeconomic status (Duncan, Magnuson & Votruba-Drzal, 2015), parental education is one of the most important and stable factors determining the family's socioeconomic position. We complement the analyses by using a complementary SES measure: the highest parental occupation measured by the *International Socio-Economic Index of Occupational Status* (ISEI-08) (Ganzeboom & Treiman, 1996). Both highest parental education and occupation are used in the analysis as metric variables. However, the findings are presented in graphical form and refer to predicted gaps between children with high, medium, and low parental education or occupation (high: 16 years or ISEI 70; medium: 14 years or ISEI 50; low: 12 years or ISEI 12).

ICT access, parental control, and student's use. Information on ICT access, parental control, and student use is retrieved from children's questionnaires. Questionnaires differ in SC2 and SC3, thus making the indicators not directly comparable. Also, not all information came from the same waves when ICT literacy was tested. If available only once over the observation window, we consider the indicator as time fixed. If available more than once, we consider indicators as time-varying and match them to the respective (or the closest) wave of testing.

ICT access. We use a dummy to proxy students' access to computers at home in grades 3, 6, and 9. In grade 3 (SC2), the dummy reports whether students used the computer at home for more than one year (=1). In grades 6 and 9 (SC3), the indicator reports whether students had their own computer at home (=1).

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[7] "(a) word processing and operating systems, (b) spreadsheet and presentation software, (c) e-mail and other communication applications, and (d) internet and internet-based search engines (Senkbeil et al., 2013)."

Table 1. Measurement of variables over panel cohorts and survey waves.

	Starting Cohort 2: Primary school			Starting Cohort 3: Secondary school				
Wave	Wave 4	Wave 5	Wave 6	Wave 1	Wave 2	Wave 3	Wave 5	Wave 6
Grade	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 9	Grade 9
Students' age	7-8	8-9	9-10	11-12	12-13	13-14	14-15	15-16
Survey year	2013-14	2014-15	2015-16	2010-11	2011-12	2012-13	2014-15	2015
Students' Competencies								
ICT literacy		**X**			**X**		**X**	
Reading competence			X	X		X		X
Math	X		X	X		X	X	
Scientific literacy		X			X		X	
Computer access, parental control[a] and type of use at home								
Computer access:								
Since when[b]		X						
Availability at home[c]					X		X	
Parents' control:								
Time[d]			X					
Type use[e]			X					
Who decide time[f]						X		
PC use type[g]:								
Intrinsic motivation		X						
Learning use		X						
Computer access at school and school characteristics								
PC availability[h]				X			X	
School track[i]					X		X	

Notes: Grey columns indicate waves and grades when ICT literacy was tested. [a] Students' evaluations (target questionnaire). [b] Dummy: 1 = Since one year or more ("*Since when do you use a computer?*") [c] Dummy: 1 = I have my own ("*Can you use a computer at home?*") [d] Four point scale from (1) completely disagree to (4) completely agree ("*My parents pay a great deal of attention to how much time I spend watching TV or playing on the computer*") [e] Four point scale from (1) completely disagree to (4) completely agree ("*My parents pay a great deal of attention to what I do on the computer*"). [f] Dummy: 1 = Both myself and my parents or my parents only ("*Who decides in your family: How much time you should spend on computer?*") [g] Composite indexes (two components) from PCA. Six items (statements on computer use). Four-point scale from (1) don't agree at all to (4) completely agree. Intrinsic motivation: (1) Fun to use; (2) interesting; (3) would use more. Learning use: (4) learn new things; (5) look up things; (6) learn a lot. [h] Information from principals' questionnaire. Composite index (one component) from PCA. Six items (school equipment): (a) *Number of computers available to students;* (b) *number of computers available to teachers;* (c) *number of computer rooms;* (d) *% of computers with less than two years (over number of computers);* (e) *the number of computers in classrooms;* and (f) *the number of full-time teachers with computer science as a school subject.* Answers are divided by the number of students in G5 and G9. [i] Dummy: 1= Gymnasium.

Parental ICT control. In grade 4 (SC2), parental control is proxied by two continuous variables measuring agreement to the following statements: (1) "my parents pay a great deal of attention to how much time I spend watching TV or playing on the computer"; and (2) "my parents pay a great deal of attention to what I do on the computer". In grade 7 (SC3), parental control is proxied by a dummy reporting if parents decide students' time on computers at home (=1).

Student's ICT use. In grade 3 (SC2), information on students' type of computer use is captured by two composite indices extracted from a principal component analysis fed with six Likert-scaled items: (a) *using the computer is interesting*; (b) *using the computer is fun*; (c) *I would like to use the computer more*; (d) *using the computer to look up things*; (e) *learning new things*; (f) *I learn a lot doing things on the computer*. The two indices measure (1) *students' intrinsic motivation for use* (a–c), and (2) *use for educational purposes* (d–f).

ICT infrastructures at school. Information on school infrastructures is retrieved from the principals' questionnaires available for SC3 only in grades 5 and 9. We construct a composite index measuring availability of ICT infrastructures and teaching staff. The index is extracted from a principal components analysis comprising six items[8]: (a) *number of computers available to students*; (b) *number of computers available to teachers*; (c) *number of computer rooms*; (d) *% of computers with less than two years*; (e) *the number of computers in classrooms*; and (f) *the number of full-time teachers with computer science as a school subject*. Whenever relevant, availability is weighted by the number of students in the respective grade (per 10 students). Information on these items is collected twice: in grade 9, when ICT literacy is tested, and in grade 5, when ICT literacy is not tested. We use information from grade 5 to proxy information for grade 6.

School track. The NEPS provides information on the school track in each wave for SC3 (grade 5 and higher). It is important to note that, although unusual, children may change track over secondary schooling. However, the tracking information is time-invariant in practice because of the school-based design of the NEPS (children who changed school were followed up individually; however, we disregarded individual follow-ups and focused on the school-based sample of children). We distinguish children enrolled in the academic track (1 = Gymnasium) from all other vocational and comprehensive schools.

Socio-Demographic Controls. We control for migration background (1 = at least one parent born abroad) in all models to have a sharper measure of SES inequality in achievement. Moreover, we control for gender to increase the precision of the estimates (even if gender is orthogonal to SES). However, in the first part of the analysis, we also show the extent and evolution of gender and migration inequalities in achievement to benchmark SES inequality.

4.3 Estimation

The analysis is divided in three parts. The first part examines the evolution of SES gaps in ICT literacy over primary and lower secondary education. We also benchmark SES gaps in ICT literacy with gaps in 'hard skills' (math, science, and reading) and gender and migration-related gaps more generally. This first part relies on Ordinary Least Squares (OLS) models that express children's achievement as a function of SES, gender, and migration background. OLS models are estimated separately in each wave, competence domain, and SES indicator (parental education or parental occupation, respectively).

The second part of the analysis combines OLS[9] regression models with the Karlson-Holm-Breen (KHB) decomposition method (Breen, Karlson & Holm, 2021) to quantify the contribution of family and

[8] We did not include the information on schools' internet access due to the very high correlation with these items ($r > 0.9$).

[9] "The KHB-method is primarily intended to be used for various variants of logit and probit models. However, it can be also used for linear regression, in which case it returns the same results as the standard technique. KHB is then just a convenient way to do the decomposition with one single command (Kohler, Karlson & Holm, 2011)."

school-level characteristics to observed SES inequality in ICT literacy. More precisely, we decompose the residual SES gaps when conditioning on gender and migration background. Note that the information regarding the school- and family environments differ in each wave (for example, school characteristics and tracking are only available in grades 6–9). Therefore, the decomposition results are not entirely comparable across grades. We consider different sets of mediators at the family level–ICT access (grades 3, 6 and 9), parental control (grades 3, 6 and 9) and students' type of use (grade 3 only). At the school level, we consider ICT infrastructures (grades 5 and 9 only). We show the results for parental education only, but results for parental ISEI were virtually identical. Figure 2 reports the main results from the models including all home- and school-level mediators available in each grade simultaneously. Table A1 in the Appendix reports results from the models including home- (altogether) and school-level mediators (with and without tracking) stepwise.

The third part of the analyses explores whether SES inequality in ICT skills still holds when comparing children with similar levels of hard skills. To this end, we use OLS models regressing ICT literacy on parental SES (parental education only), gender, migration background, and with and without including z-standardized scores in hard skills among the covariates. We consider z-standardized scores in math, science, and reading as measured in the grade before (preferable) or in the same grade when ICT literacy was tested (whenever available).[10] We run the analysis separately in grades 3, 6, and 9.

All the analyses are implemented using NEPS design weights and/or longitudinal weights that account for sampling design and attrition (at least in part).

5 Findings

5.1 SES inequality in ICT literacy

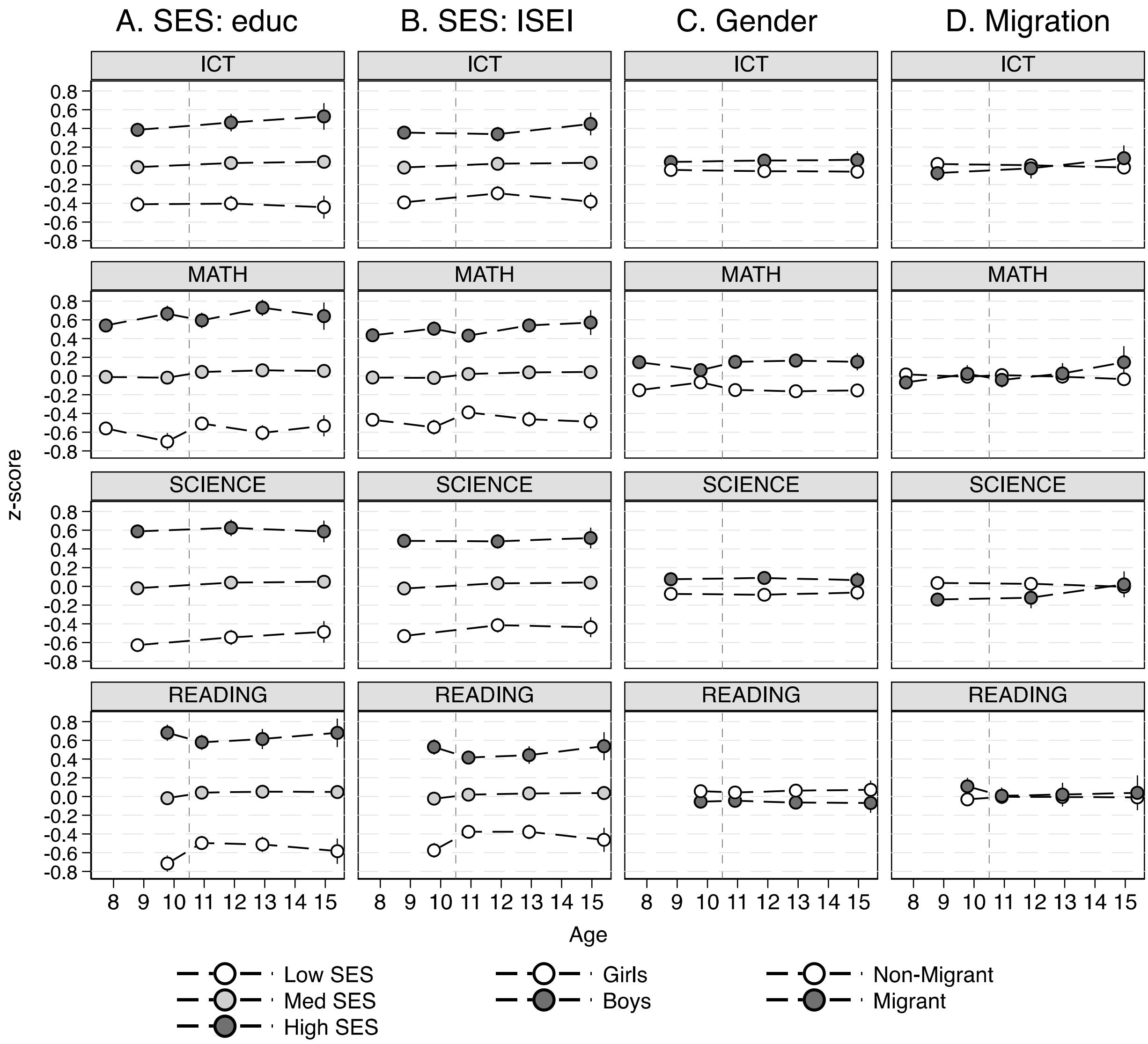
Figure 1 (Panels A–B) shows the evolution of SES inequality in ICT literacy, math, science and reading between grades 2 and 9 (age 7–16 approximately). The figure reports predictions for children with low- (12 years of education or ISEI 30), medium- (14 years or ISEI 50), and high - SES parents (16 years or ISEI 70). The results are striking. SES inequality in ICT literacy is apparent as early as in grade 3 (age 8) of primary school. When looking at differences by parental education (Panel A), the early gap amounts to around .8 SD comparing children with high and low educated parents (high-low gap); this high-low gap increases to .9 SD only by the end of lower secondary schooling (grade 9). Panel B documents a virtually identical pattern when looking at differences by parental occupational status. Hence, there is little evidence that SES gaps in ICT increase or decrease over primary and lower secondary schooling in Germany.

It is worth noting that SES gaps in ICT literacy are slightly less pronounced than gaps in hard skills, like reading, math, or science. This is particularly true in the case of parental education (when looking at the parental occupational status differences are less visible). However, these slight differences do not build a strong case for lower SES inequality in ICT compared to other domains, especially if we consider that differences across domains are not formally comparable. Aside from the magnitude of SES differences across domains, there is a striking similarity in how such differences evolve over

[10] The only exception is reading in the equation predicting ICT literacy in grade 3. Unfortunately, reading scores were only available for the grade following the grade of testing for ICT literacy. The inclusion of z-standardized scores measured in different grades in the right-hand side of the equation resulted in a substantial drop in sample size in all grades. Appendix Table A2 shows estimate of the total SES-ICT literacy association in the full sample and the restricted sample (hard skills) for comparison. Notwithstanding the lower sample size, SES gradients are very similar in the full and restricted samples in each grade.

schooling. Social inequality in hard skills does not seem to change much after grade 2 of primary education; instead, like for ICT literacy, SES inequality remains constant over schooling. All in all, the strength and evolution of SES gaps in ICT literacy seem not to differ much compared to classical competence domains that were widely analysed in the previous research.

Figure 1. SES (parental years of education and ISEI), gender and migration gaps in standardised ICT, math, science and reading competencies.



Notes: Predictions from OLS regression models estimated separately by wave, competence domain, and SES indicator. All models include simultaneously gender, migration background, and parental SES (parental education or ISEI) among the covariates. Scores are standardised by wave. 95% confidence intervals shown. Vertical dashed lines separate cohorts (SC2 grade 2-5, and SC3 grade 5-9). Data weighted.

Source: Authors' elaboration from NEPS

Figure 1 (Panels C–D) also shows the evolution of gender and migration-related inequality in the same competence domains and time window for comparison. Comparing SES inequality vis-à-vis gender and migration inequalities also results in a striking portrait. SES gaps in ICT literacy and other domains are astounding in effect size compared to gaps by gender or migration background. Boys seem to perform better than girls in math, mirroring a common finding in the literature. This gap remains constant up to grade 9 but strikingly lower in magnitude (0.35 SD approximately) compared to gradients by parental education or occupational status. All in all, there are no meaningful differences by gender or migration background in math, science, or reading. ICT literacy is no exception; boys and girls seem to perform equally on average, as do migrants and natives. What is more, inequality by gender or migration background in ICT literacy (like science and reading) does not emerge as children navigate throughout primary schooling and even when they are tracked in secondary schooling.

5.2 Drivers of SES inequality in ICT literacy

This section reports results from the decomposition of SES gaps in ICT in grades 3, 6, and 9. As shown in Figure 2, in grade 3, only around 4% of the total association between parental SES and ICT literacy ($\beta = 0.108$, see Table A1 in the Appendix) is mediated by family-level characteristics, that is computer access at home (-0.4%), parental control over ICT timing (0.1%), use type (2.68%), and students' intrinsic motivation to use ICT and learning use (1.9%). Moreover, this small percentage is statistically indistinguishable from 0 at the conventional level ($p < 0.05$, see Table A1 in the Appendix). Thus, access, parental control, and children's motivation and use patterns seem to not substantially mediate the observed SES gap in ICT literacy in grade 3.

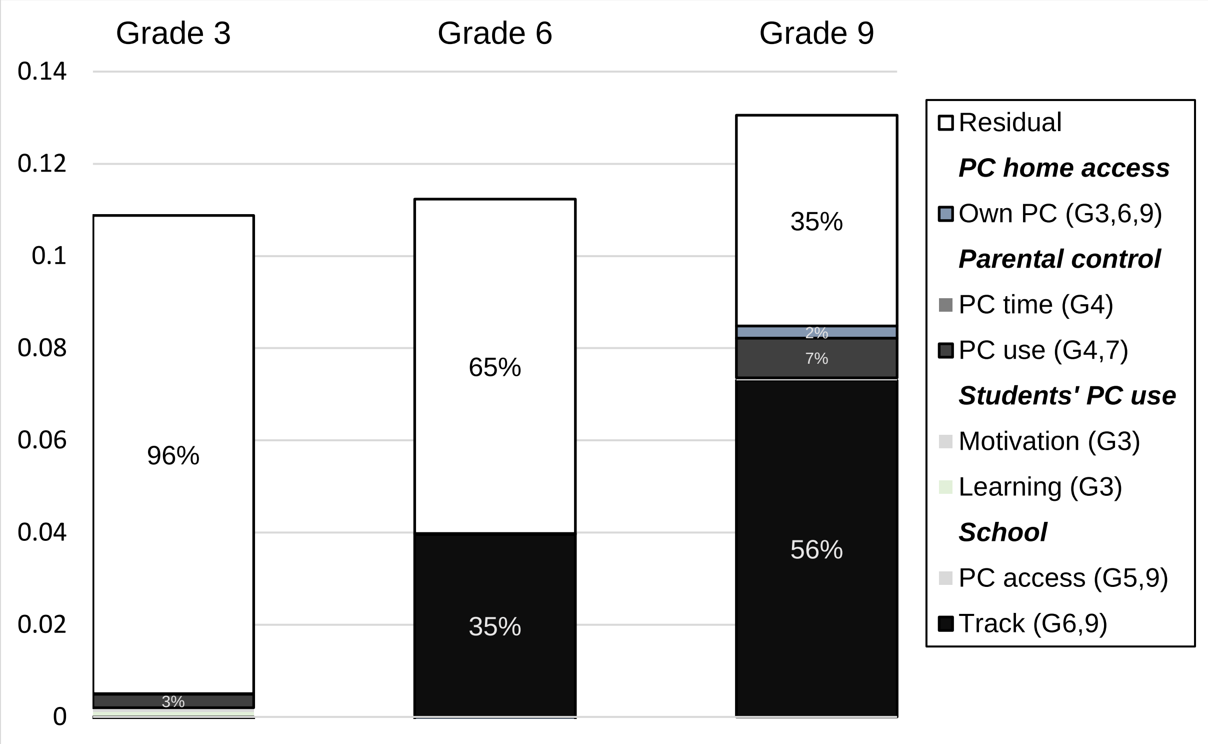
The decomposition in grade 6 offers a different picture. It is important to keep in mind that, from grade 5, students are tracked in academic or vocational schools with a very different composition of students' SES and ability. Students' sorting into academic and vocational tracks account for around 35% ($p < 0.000$) of the SES-ICT literacy association in grade 6 ($\beta = 0.113$). School track is the only characteristic explaining SES inequality; neither family-level factors nor ICT infrastructures at school explain SES gaps in grade 6.

In grade 9, home- and school-level characteristics altogether explain 65% ($p < 0.000$) of the observed SES gap in ICT literacy ($\beta = 0.131$). However, school tracking alone accounts for 56% of the SES gap in ICT literacy ($p < 0.000$), while school ICT infrastructures do not play any role (0.5%). This result resembles what was found in grade 6. The availability of computers at home and parental control account for only around 9% of the observed gaps.

Although comparability across grades is limited, our analysis suggests that selection into different school tracks accounts for the biggest chunk of the digital divide found in secondary schooling (grades 6 and 9). School tracking from primary to secondary schooling strongly selects students by academic skills and parental SES and likely diminishes students' heterogeneity by ability and SES within the tracks. Therefore, it is not surprising that neither family nor other school-level characteristics play a role beyond tracking. Nonetheless, the increased proportion of SES gaps explained by tracking between grades 6 and 9 may be interpreted as indirect evidence that tracking may be a driver of SES inequality over secondary schooling beyond selection. However, the present analyses do not allow to distinguish between mechanisms of selection and causation related to the role of tracking.

It is worth noting that the absence of mediation by ICT infrastructures at school holds even when we exclude the school track among the mediators (see Appendix Table A1). Home-level characteristics also explain SES inequality in ICT literacy, but to a much lower extent, around 4% to 9% in grades 3 and 9, respectively.

Figure 2. Decomposition of the total SES-ICT literacy association in grades 3, 6, and 9: the role of family and school-level factors.



Notes: Estimations from the linear KHB decomposition method. All models control for gender and migration background. Data weighted.

Source: Authors' elaboration from NEPS

5.3 Is SES inequality in ICT literacy explained by SES inequality in hard skills?

General cognitive ability or intelligence load on many meta-competencies including problem-solving, abstract reasoning, and verbal and numeracy skills. Therefore, general intelligence also correlates with manifest competencies like math, science, or reading (Rindermann, 2007). ICT literacy may be no exception. SES inequality in ICT literacy may reflect hidden, higher-order differences in general cognitive ability. So, does SES inequality in ICT skills still hold when comparing children with similar levels of hard skills? Are the mechanisms explaining SES inequality in ICT literacy unique? Or are there common mechanisms explaining SES inequality in ICT literacy and hard skills?

As Table 2 shows, we could not detect any SES difference in students' ICT literacy when conditioning on hard skills. This result holds in all grades, thus suggesting that parental practices explaining SES gaps in hard skills (e.g., educational activities and behavioural strategies) might also explain SES inequality in ICT literacy. However, these results are also compatible with the idea that strong competencies in reading, math, and science help develop ICT literacy via cross-fertilisation dynamics. These results are not surprising if we consider that ICT literacy and hard skills are moderate to highly correlated[11] (*r* ranging from 0.4 to 0.7) and both part of a higher-order hierarchy of general cognitive

[11] $r_{ICT\text{-}math}$ = .42 (grade 3); .56 (grade 6); .62 (grade 9); $r_{ICT\text{-}science}$ = .48 (grade 3); .62 (grade 6); .69 (grade 9); $r_{ICT\text{-}reading}$ = .41 (grade 3); .54 (grade 6); .61 (grade 9).

abilities. Additional analyses predicting proficiency in hard skills (math, science, reading) conditioning on the remaining domains and ICT literacy show that a statistically significant and sizeable residual association between SES and hard skills remains. Altogether, these results may suggest that hard skills themselves might be antecedent and help the development of ICT literacy through cross-fertilisation (and not the other way around).

Table 2. SES gradient in z-standardized ICT literacy in grades 3, 6, and 9 (total and residual after accounting for hard skills).

	Grade 3 (SC2)		Grade 6 (SC3)		Grade 9 (SC3)	
	Total	Residual	Total	Residual	Total	Residual
Parental SES	0.102***	0.01	0.117***	0.005	0.129***	-0.006
	(0.009)	(0.009)	(0.010)	(0.008)	(0.017)	(0.013)
Hard Skills	No	Yes	No	Yes	No	Yes
N	4,460	4,460	3,309	3,309	3,177	3,177

Notes: Results from linear regression models. All models control for gender and migration background. Parental SES measured by parental years of education. Z-standardised scores in hard skills (math, science, and reading) are included simultaneously. Grade 3: math measured in G2; science in G3; reading in G4. Grade 6: reading and math measured in G5; science measured in G6. Grade 9: reading and math measured in G7; science measured in G9. Weighted data. Robust standard errors in parentheses. Significance levels: * p<0.05, ** p<0.01, *** p<0.001. Data weighted.

Source: Authors' elaboration from NEPS

6 Discussion and Conclusion

This article analysed the roots, the evolution, and the drivers of SES inequality in ICT literacy over primary and lower secondary education in Germany. Our analyses added to the interdisciplinary literature on social stratification, skill formation, and the digital divide in several ways. First, we benchmarked SES gaps in ICT literacy with gaps by gender and migration background. The sociological scholarship is often concerned with gender and migration-related inequalities in educational achievement. However, our study showed that gender and migration-related inequalities are by far lower compared to inequalities by socioeconomic background. Second, we benchmarked SES inequality in ICT literacy with inequalities in traditional academic domains, like mathematics, science, and reading. This direct comparison is of theoretical relevance because traditional academic domains are often subject to formal teaching in the classroom, while ICT is often not directly taught in school. Third, we moved beyond a static portrait of SES gaps in ICT literacy among adolescents as measured by ICILS or PISA data. Rather than considering adolescence as the origin of a stratification process unfolding in later life, we opened the possibility that adolescence may represent the end of a stratification process starting already in primary school. Fourth, we attempted to establish which family- and school-level factors contribute to SES inequality in ICT literacy at different ages.

The article reported five main findings: (1) SES gaps in ICT literacy exist as early as age 8–9 (grade 3) and are similar in magnitude compared to gaps in hard skills; (2) SES gaps in ICT literacy remain stable over primary and lower secondary schooling up to age 14–15 (grade 9); (3) family and school ICT access and use do not substantially explain SES gaps in ICT at any age; (4) school tracking is a relevant (although not necessarily a causal) pathway through which SES inequality manifests in secondary school; (5) the SES gap in ICT literacy does not hold after conditioning on previous students' differences in hard skills.

Sizeable and persistent SES gaps in ICT literacy mirror the previous scholarship documenting that SES gaps in hard skills emerge in early childhood and remain stable thereafter (von Hippel & Hamrock, 2019; Bradbury et al., 2015). This finding was also documented in Germany and with respect to a variety of competence domains (Skopek & Passaretta, 2021; Linberg et al., 2019). This article highlighted that ICT literacy is no exception; the roots of social inequality in this new and allegedly essential set of skills for the digital age may be sought in the early stages of children's lives.

The tiny contribution of ICT access and use to social inequality in ICT literacy is surprising. On the one hand, the minor role of ICT infrastructures in school is in line with the provocative argument put forward by the Coleman report in the 60s, that is, family environments (within-school inequality) are more important than school differences (between-school inequality) in explaining SES inequalities in the achievements of school-age students. On the other hand, differences in ICT access, parental control, and students' use at home do not explain SES gaps either.

We found that tracking (from grade 4) accounts for a big chunk of SES inequality in ICT literacy in lower secondary education. This is likely due to selection processes that lead high achievers, high ability, and high SES students to attend the academic track, which also gives the best opportunities for learning and cognitive development in Germany. Indeed, selection into school tracks is based on students' ability but also SES (irrespective of ability) in Germany. At the same time, the observed increase in the mediating role of tracking from grade 6 to 9 suggest that tracking may be driving achievement beyond selection, for example due to curricular differentiation and peer effects. However, these findings cannot disentangle selection or causation mechanisms behind the importance of tracking, nor they can disentangle the importance of inequality mechanisms operating in- and out of the school or be generalized to countries without early tracking.

The 'absence of mediation' of school and family factors related to ICT access and use may also result from poor measurement. Measurement error in the family- and school-level indicators would artificially deflate the importance of these factors in explaining the observed SES gaps in ICT literacy. Have we had more comprehensive information on schools' ICT teaching plans, staff training, and own perception of competencies, the role of school characteristics would be likely stronger (European Commission, 2013; 2019; Gerick et al., 2017). The same rationale applies to the minor role of ICT access, parental control, and student's ICT use at home. However, it is unlikely that our findings are only driven by measurement error for two reasons. First, our composite indices of school ICT infrastructures and ICT use at home are rich. Second, we found SES gaps in the patterns of ICT use at home and ICT infrastructures at school, which would be very unlikely if these measures were completely flawed.

Finally, we could not detect social inequality in ICT literacy when looking at similarly performing children in traditional competence domains like math, science, and reading. This finding suggests that the very mechanisms driving SES gaps in digital skills may be similar to those driving socioeconomic inequalities in hard skills. It might be the case that social inequality in ICT literacy simply echoes common inequality mechanisms due to family environments and investments that are responsible for unequal proficiency in hard skills. Future studies may dig deeper into these dynamics to understand whether and to what extent mechanisms driving socioeconomic inequality in ICT literacy and hard skills differ in any meaningful way.

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8 List of abbreviations and definitions

ICT	Information and Communications Technology
SES	Socio-Economic Status
ISEI	International Socio-Economic Index of Occupational Status
NEPS	National Educational Panel Study
ICILS	International Computer and Information Literacy Study
ETS	Educational Testing Service
PISA	Programme for International Students Assessment
SC2	Starting Cohort 2
SC3	Starting Cohort 3
TILT	Test of Technological and Information Literacy
KHB	Karlson-Holm-Breen
PC	Personal Computer

9 Annexes

9.1 Annex 1. Robustness checks

Table A1. Linear KHB decomposition of SES gaps (parental years of education) in z-standardized ICT literacy by groups of mediators/drivers and grade.

SES-achievement association	Grade 3 (SC2)		Grade 6 (SC3)		Grade 9 (SC3)	
	Coef.	SE	Coef.	SE	Coef.	SE
	Home (access, control, use)					
Total	0.108***	(0.011)	0.113***	(0.011)	0.128***	(0.016)
Residual	0.104***	(0.011)	0.111***	(0.011)	0.116***	(0.016)
Difference	0.005+	(0.002)	0.002	(0.002)	0.012***	(0.003)
Mediation (%)	4.28+		1.46		9.47***	
N	3,473		2,943		3,086	
R^2	0.08		0.07		0.11	
	Home + School (access)					
Total			0.111***	(0.015)	0.131***	(0.020)
Residual			0.111***	(0.015)	0.114***	(0.020)
Difference			0.000	(0.002)	0.017**	(0.005)
Mediation (%)			0.14		12.82**	
N			1,606		1,576	
R^2			0.06		0.13	
	Home + School + Tracking					
Total			0.111***	(0.014)	0.131***	(0.020)
Residual			0.073***	(0.015)	0.046*	(0.019)
Difference			0.038***	(0.006)	0.085***	(0.010)
Mediation (%)			34.59***		64.99***	
N			1,606		1,576	
R^2			0.13		0.22	

Notes: All models control for gender and migration background. Robust standard errors in parentheses; significance levels: +p<0.10, * p<0.05, ** p<0.01, *** p<0.001. Data weighted.

Source: Authors' elaboration from NEPS

Table A2. SES gradient (parental years of education) in z-standardized ICT literacy in the full sample (Figure 1) and the restricted subsamples for the decomposition analyses (drivers) and the analyses conditioning on hard skills (hard skills) by grade.

	z-standardized ICT literacy		
	Full sample	Restricted subsamples	
		Drivers	Hard skills
Grade 3 (SC2)			
Parental SES	0.099***	0.108***	0.102***
	(0.009)	(0.011)	(0.009)
N	5,102	3,473	4,460
Grade 6 (SC3)			
Parental SES	0.108***	0.111***	0.117***
	(0.010)	(0.015)	(0.010)
N	3,462	1,606	3,309
Grade 9 (SC3)			
Parental SES	0.121***	0.131***	0.129***
	(0.015)	(0.022)	(0.017)
N	3,310	1,576	3,177

Notes: All models control for gender and migration background. Robust standard errors in parentheses; significance levels: * p<0.05, ** p<0.01, *** p<0.001. Data weighted.

Source: Authors' elaboration from NEPS

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