The evolution of the association between ICT use and reading achievement in 28 countries

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The evolution of the association between ICT use and reading achievement in 28 countries

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Abstract

This paper examines the evolution of 15-year-old students' use of ICT for leisure and for learning at school and at home between 2009 and 2018. It also considers how the association between different forms of ICT use and reading achievement evolved over the same period. Results indicate that in 2018 15-year-old students used ICT for leisure and for learning more than their counterparts did in 2009 and that the increase was especially marked when considering ICT used for learning (both at school and at home). Boys increased their use of ICT for leisure and their use of ICT for learning at school more than girls did. Trends in ICT use did not differ by socio-economic condition. Over the same period, no quantitatively meaningful changes in reading achievement were observed. In line with the previous literature, we find that the association between different forms of ICT use and reading achievement takes an inverted U shape, with students engaging in low and high levels of use having lower levels of reading achievement than students engaged in medium levels of use. Over time, the association between different uses of ICT and reading achievement changed and became more positive at low levels of use and less negative at high levels of use. However, the large and rapid increases in levels of use observed between 2009 and 2018 led to more students being located in the 'high levels of use' category. The cumulative, contrasting effects of changes in levels of use and changes in the association between ICT use and reading achievement led to stable levels of achievement at the population level.

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Introduction

Past research has considered the effects of ICT use on children's academic skills, non-cognitive skills, and social and emotional well-being (Steffens, 2014; Biagi & Loi, 2013; Vedechkina & Borgonovi, 2021; Agasisti, Gil-Izquierdo & Han, 2020; Gubbels, Swart & Groen, 2020; Kunina-Habenicht & Goldhammer, 2020; Orben & Przybylski, 2019). Findings from such literature generally paint a mixed picture with some studies detailing worse outcome among children who use ICT for leisure or for academic activities, and others detailing no differences in outcomes between those who use ICT and those who do not. Such differences have been considered to arise because of differences in associations depending on user characteristics, intensity of use and content of use (Vedechkina & Borgonovi, 2021).

In this work we exploit unique repeated cross-sectional data from the Programme for International Student Assessment on reading achievement and ICT use, to derive indicators of ICT use that are comparable over time and explore variations in the evolution of the association between different forms of ICT use as well as the changing association between ICT use and reading achievement. The contribution of our work is twofold. First, we map changes between 2009 and 2018 in the use of ICT among large-representative samples of 15-year-old students in 28 countries worldwide. We consider changes in three forms of ICT use: ICT use for leisure, ICT use for learning in school, and ICT use for learning at home. We highlight changes in patterns of use across key demographic groups: boys and girls and students with and without at least one parent educated at the tertiary level. Second, we identify changes in the contemporaneous association between different forms of ICT use and the reading achievement of 15-year-old students and if such association changed between 2009 and 2018.

We consider the association between ICT use and reading achievement because reading proficiency is necessary to acquire knowledge, and as such, is a precondition for individuals' success in other academic subjects, education and beyond (Cunningham & Stanovich, 1998; Smith, Mikulecky, Kibby, & Dreher, 2000). Moreover, the development of reading proficiency is especially dependent on the activities children engage in outside of school, such as, for example, if they read in their free time (Clark & Rumbold, 2006). There is evidence that patterns of engagement with reading activities changed markedly in the past decade, at least in part as a result of widespread use of technologies (Hughes-Hassel & Rodge, 2007; Loh & Sun, 2019; Singer & Alexander, 2017). Teenagers report lower overall levels of reading for enjoyment and increases in the amount of reading they conduct using

digital devices (Clark & Rumbold, 2006; Singer & Alexander, 2017; Sullivan & Brown, 2015).

Past Literature

Digital technologies are becoming increasingly widespread in societies, and new devices such as smartphones and smartwatches allow individuals to access information anytime, anywhere. The increase in the availability of digital technologies and diversification of devices and applications, coupled with the recognition that mastering such technologies is important in the labor market (Carretero, Vuoricari & Punie, 2017), has prompted many educators to promote the use of ICT in schools (Redecker, 2017). The aim of such efforts is to exploit potential benefits of ICT to promote students' learning but also to equip students with digital literacy, a key competence for successful participation in society and the labor market (Binkley et al., 2012; Fraillon, Schulz & Ainley, 2013).

Although in recent years considerable investments in ICT resources have been made in many education systems, there is little evidence about how much they changed the practice of use of ICT for learning (OECD, 2015). Moreover, although there is evidence on the contemporaneous association between ICT use and academic achievement among specific cohorts of students, it remains unclear how this association evolved over time following changes in patterns of use, at the individual and collective level, and development in technologies. This is especially relevant because empirical analyses indicate that the association between ICT use and achievement follows an inverted U shape. For example, the literature indicates that students who use ICT for leisure and for school activities in moderation achieve at a higher level than those who use ICT rarely or intensively in Germany, Finland and the Netherlands (Steffens, 2014; Gubbels et al., 2020). Changing patterns of use and changes in the intensity of use over time could therefore lead to changes in the association between ICT use and reading achievement as increasing numbers of children move from low to moderate use but also from moderate to high levels of use. However, the very shape of the association could change because effects could be relative, rather than absolute. This could occur if, for example, children who use ICT extensively have the tendency to develop behaviors that are associated with low achievement (such as multitasking, not reading instructions) and only when large numbers of children engage in such practices educators recognize the problem and put in place strategies to remedy the situation.

Becoming a proficient reader requires the mastery of progressively more difficult tasks (Kieffer, 2012). In particular, when students move from primary into secondary school, the knowledge demands they experience and the tasks they have to master become harder, while the level of support they receive typically decreases (Alexander & Jetton, 2000; Ehri & Snowling, 2004). At higher grade levels being a skilled reader involves being an independent reader who is able to deploy effective reading strategies to access texts of increasing complexity and variety (OECD, 2019). As such, ICT use could be useful to ensure that students put the effort and energy that are necessary to persist in their studies by promoting their engagement and motivation, especially when ICT plays a large part in young people's non-academic lives (Prensky, 2001).

It has been argued that in a world with a high degree of ICT penetration, young people's interest in and engagement with ICT stands in marked contrast to their perception of curricular content and that ICT should be embedded in teaching as a way to satisfy the intellectual, emotional and motivational needs of students (Tapscott, 1998). The adoption of features typical of video-games or other ICT applications for learning both in classrooms and for self-study has therefore been considered as a way to increase interest, making learning more enjoyable for students (Prensky, 2001). Interestingly, many youngsters prefer to use paper rather than digital devices to learn. This might indicate that although they may feel motivated by ICT in the abstract, they may also experience greater cognitive strain and fatigue being associated with using ICT for learning (Woody et al. 2010). Moreover, there may be a disparity between the sophisticated technological opportunities available in day to day settings and the unsophisticated technology use for learning promoted by schools and educators, which could lead to alienation and disaffection among students (Prensky, 2005).

At the same time, because ICT allows individuals to perform multiple tasks using the same medium, using ICT for learning could lead to distraction, either because students might try to multitask, or because they might switch their attention across several tasks. Multitasking is defined as the simultaneous processing or execution of two or more tasks, although from a behavioral and neurocognitive perspective multitasking can be assimilated with rapid task-switching (Vedechkina & Borgonovi, 2021). When individuals engage in different tasks in rapid succession, their attention is inevitably shared across tasks (Colom et al., 2010; Foerde et al., 2006) leading to poorer academic result, attitudes, and perceived learning (Van Der Schuur et al., 2015). ICT multitasking may limit the amount of attention available for the simultaneous processing of academic content (Junco & Cotten, 2012) and displace the amount of time dedicated to academic activities (Fox et al., 2009).

Proponents of the displacement hypothesis predict that ICT use will have negative effects on reading achievement if time spent on ICT devices is time not spent on activities that are strongly and positively associated with improved reading abilities such as, for example, reading for enjoyment (Weis & Cerankosky, 2010) and sleep (King et al., 2013). As such, they indicate that the observed association between specific forms of ICT use and reading achievement will be the result of the type of activities that each form of ICT use displaces. This means that what matters when considering the effect of using ICT for reading achievement is the relative productivity of time investments in the use of specific forms of ICT compared to other time investments.

The displacement hypothesis could explain the finding in the literature detailing a strong negative association between the use of ICT for learning and academic achievement but no association or even a positive association between the use of ICT for leisure and academic achievement (OECD, 2015). This could occur if the use of ICT for learning displaced engagement in self-study but the use of ICT for leisure did not, because it substituted other types of leisure activities, and learning through ICT was less positively associated with reading achievement than learning that occurs without the aid of ICT. It could also explain the inverted U shape identified in the literature, indicating that individuals with no or extensive use of ICT have lower achievement than those with moderate levels of ICT. High levels of ICT use are in fact most likely to displace other activities. By contrast, because the use of ICT, whether for leisure or for learning, generally involves reading, medium levels of use could complement other reading activities and, as such, be associated with better reading achievement compared to no or very limited use.

There is empirical evidence pointing towards screen inferiority with respect to the use of digital environments for learning. Although some studies have found equivalence between learning processes that occur using paper aids and computerized aids (Ball & Hourcade, 2011; Margolin et al., 2013; Murray & Pérez, 2011; Salmerón & García, 2012), the literature generally indicates that learning from continuous texts is less effective when performed using computers rather than paper (Ackerman & Goldsmith, 2011; Daniel & Woody, 2013; Mangen et al., 2013). Crucially, studies examining the relative learning gain obtained through paper-based and computerized study identify screen inferiority even when learning is evaluated using tests that contain stimuli that require the use of ICT devices and ICT familiarity, such as comprehending texts containing hypertexts (DeStefano & LeFevre, 2007), sound, animation, and interactive reading (Mayer et al., 2001). Therefore, the use of ICT for learning could remain less effective in promoting reading achievement even as

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computer-based tests are used to assess reading achievement. Screen inferiority in the development of text comprehension abilities has been hypothesized to be the result of technological disadvantages inherent to some digital devices as well as physical discomfort, such as eye strain (Benedetto et al., 2013; Li et al., 2013; Leeson, 2006). However, screen inferiority has been identified even when modern devices designed to overcome technological and physical disadvantages are used (Daniel & Woody, 2013; Gu et al., 2015).

The literature on the use of ICT for leisure, such as the literature on videogames, suggest that the use of ICT for leisure can have cognitive benefits (Feng & Spence, 2018): for example videogames promote informal exploratory learning and can enhance problem-solving skills (Greenfield et al., 1994). Proponents of the learning to learn hypothesis argue that gaming can be used to enhance broad aspects of cognition, and can lead to general improvements in attentional capacity, cognitive control, pattern recognition, problem-solving abilities, and more efficient learning strategies (Bavelier et al., 2012a; Green & Bavelier, 2012; Prensky, 2012). In fact, numerous studies have identified improvements on specific measures of visuospatial cognition after short periods of playing video games (see Vedechkina & Borgonovi, 2021 for a review). Although the literature on the cognitive consequences of videogame use is by far the largest strand of the broader literature on ICT used for leisure and academic achievement, there have been studies examining the association between social media use and academic results. Findings from the literature on social media are also mixed: some studies suggest that engaging in social media could improve some aspects of academic achievement (Huang, 2018) and cognitive skills (Alloway & Alloway, 2012), while others point to a positive correlation with literacy but negative with average grades (Liu et al., 2017), or even a negative association (Cudo et al., 2019).

The cognitive benefits of ICT for leisure detailed above are likely to be especially important when reading achievement is assessed using computer-based tests (Borgonovi, 2016). Digital reading requires a unique set of skills (Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2012; Leu et al., 2015), comprising not only the capacity to comprehend and interpret extended pieces of continuous texts, but also the capacity to analyze, synthesize, integrate and interpret relevant information from multiple texts and information sources (Rouet, 2006; Spiro, Deschryver, Hagerman, Morsink, & Thompson, 2015). As digital technologies and their use become pervasive, teenagers are increasingly required to apply their skills to read digital material to solve problems on computers (Coiro, Knobel, Lankshear, & Leu, 2008; Kemp, 2011; Wirth & Klieme, 2004) and, as such, the cognitive benefits of ICT use may become more pronounced.

Aim and Research Questions

Informed by the rich literature on the association between ICT use and achievement, the main objective of this paper is to identify how the use of ICT for leisure, ICT for learning at school and ICT for learning at home changed between 2009 and 2018 and how the association between different forms of ICT use and reading achievement changed over time. To do so, we develop comparable measures of ICT use and relate these measures to reading achievement as measured through the PISA large-scale standardized assessment. The empirical analyses answer the following questions:

1) Did the use of ICT for learning at school and at home and the use of ICT for leisure among 15-year-old students increase between 2009 and 2018 and, if so, which form of use increased the most?

2) Did changes in patterns of use differ across boys and girls and across students with and without highly educated parents?

3) Did the association between different forms of ICT use and reading achievement change between 2009 and 2018?

Data

PISA

PISA is a low-stake international large-scale assessment that has been administered to samples of 15-year-old students every three years since 2000. PISA involves large-representative samples of students from countries that vary widely in cultural, linguistic and social background, level of economic development, technological adoption and in how the education system is organized.

Participants

Our data come from the 2009, 2012, 2015 and 2018 editions of PISA. All cases used in our analyses were extracted from the public-use files, which can be downloaded from: http://www.oecd.org/pisa/data. Weighted samples are representative of students who are enrolled in grade 7 or above and are between 15 years and 3 months and 16 years and 2 months at the time of the assessment administration (generally referred to as 15-year-olds in this work). In each cycle, PISA participants are selected from the population of 15-year-old

students in each participating country according to a two-stage random sampling procedure. The PISA technical standards require that in a first stage, a stratified sample of schools is drawn and that, in a second stage, students are selected at random in each sampled school.

The number of countries participating in the PISA study widened over time: in 2009 65 education systems took part in the study and by 2018 79 did. Since our analyses aim to identify changes in the use of ICT over time and changes in the strength of the association between ICT use and reading achievement, our sample is restricted to the subset of countries that participated in each of the four PISA editions that were administered between 2009 and 2018. Furthermore, we removed from our sample all students who reported having an immigrant background. This is because PISA allows to capture the characteristics of students with an immigrant background only in part, and between 2009 and 2018 the composition of foreign-born populations changed greatly in many OECD countries. Our analytic sample includes a total of 702,023 students in 28 countries over the four cycles.

Instruments

The PISA program consists in a series of repeated cross-sectional surveys administered every three years. In each assessment cycle participating students take part in a timed, two-hour test. After they complete the test they have a short break and then complete a questionnaire. The intention of the study is to collect information that can be compared across participating countries but also over time. In order to achieve this, in each cycle, the test contains some questions that were administered in previous cycles and the remaining new questions are selected with the aim of adhering to the underlying assessment frameworks in the assessment domains (such as reading, mathematics and science). Furthermore, statistical tests are conducted to identify the psychometric properties of each question during a field trial administration. Questions not meeting standards are discarded and not used in the main study administration.

The key assessment domains in PISA are reading, mathematics and science. Each participating student is administered, at random, a test form containing a range of assessment material. In each cycle, one of the three key PISA domains is the main domain and a larger set of test questions in that domain is administered. Reading was the main assessment domain in 2009 and 2018, mathematics was the main domain in 2012 and science was the main assessment domain in 2015. Until 2012 the core assessment was delivered as paper-and-pencil while in 2015 PISA transitioned to computer-based delivery. A mode effect study was conducted to estimate if the move to computer delivery influenced results thus limiting the

comparability of achievement scores over time (OECD, 2016). The study indicated that assessment instruments were comparable in the two modes of administration.

In PISA, background questionnaires complement the test. The main student questionnaire is designed to capture students' demographic and socio-economic characteristics, including parental education and occupational status, their and their parents' country of birth, household possessions. Moreover, students are asked detailed questions about their attitudes towards learning, their engagement in academic activities, as well as information about their school, peers and teachers. PISA is a flexible instrument, meaning that, on top of the main student questionnaire administered to all students in all countries, countries can decide to administer additional optional questionnaires developed at the international level, as well as national options. Among the international options that have been regularly offered for administration is the ICT questionnaire. The questionnaire was designed to identify students' use of ICT for leisure and for learning, as well as students' attitudes towards various technologies.

Variable Descriptions

As an indicator of academic achievement, we use the PISA reading achievement scores. PISA test scores are included in the PISA datasets as multiply imputed measures of proficiency ("plausible values"). PISA test scores are based on item-response-theory scaling procedures and are comparable across students taking different test forms and taking the test in different editions. Reading was the main assessment domain in 2009 and 2018, meaning that a large set of questions in the PISA test were reading questions. In 2012 and 2015, when mathematics and science were the main assessment domains, the amount of assessment tasks in reading was smaller but estimates remain comparable with 2009 and 2018. In 2009 and 2012, a set of five plausible values were estimated while in 2015 and 2018 a set of 10 plausible values were reported.

We consider three types of use of ICT: ICT used for leisure, ICT used for academic purposes at home and ICT used for academic purposes at school. Students were asked to report the frequency with which they engaged in a range of activities using the following thresholds: never or hardly ever; once or twice a month; one or twice a week; every day or almost every day.

Activities considered when probing students to report their leisure ICT engagement at home included: (1) playing one-player games; (2) playing collaborative online games; (3)

using e-mail; (4) chatting online; (5) browsing the internet for fun; (6) downloading music, films, games or software from the Internet;

Activities considered when probing students to report their ICT engagement for school work at home included: (1) browsing the Internet for schoolwork (e.g. preparing an essay or presentation); (2) using e-mail for communication with other students about schoolwork; (3) using e-mail for communication with teachers and submission of homework or other schoolwork; (4) downloading, uploading or browsing material from your school's website (e.g. time table or course materials); (5) check the school's website for announcements, e.g. absence of teachers; (6) doing homework on a computer.

Activities considered when probing students to report their ICT engagement at school included: (1) chatting on line at school; (2) using e-mail at school; (3) browsing the Internet for schoolwork; (4) downloading, uploading or browsing material from the school's website; (5) posting your work on the school's website; (6) playing simulations at school; (7) practicing and drilling, such as for foreign language learning or mathematics; (8) doing individual homework on a school computer; (9) using school computers for group work and communication with other students.

Gender is a key individual-level independent variable. This variable was reported by students in the background questionnaire. In all models we report differences in outcomes associated with being a female. As an indicator of socio-economic status that can be easily compared across countries and over time, we introduce an indicator that takes 1 when students report in the main questionnaire that at least one of their parents obtained tertiary level qualifications and value 0 whenever students report that neither of their parents obtained tertiary level qualifications.

Methods

Measurement Invariance and Scaling the Main Constructs

The aim of our work is to examine differences in ICT use across years combining information from 28 countries. This is possible only if measurement invariance (also referred to as measurement equivalence in the literature) is established. Meaningful comparisons of means or associations like covariances and unstandardized regression coefficients across time points from different countries can only be conducted in the presence of measurement equivalence (Meredith, 1993; Steenkamp and Baumgartner, 1998; Davidov et al., 2014; Pokropek et al., 2017). In other words, measures of ICT use that are comparable across countries and over time are needed to identify trends in different forms of ICT use, if these

differ across population groups and if the association between ICT use and reading achievement changed between 2009 and 2018.

The classical approach to test measurement invariance is Confirmatory Factor Analysis (CFA) assuming full metric or full scalar invariance. However, full metric and scalar invariance are rarely achieved in practice. A solution is to adopt a partial equivalence approach. In the partial equivalence approach some item parameters are constrained to be equal across groups, whereas others are estimated freely, therefore relaxing some of the assumptions and constraints needed in the classical, full invariance analysis framework. Indicators constructed using partial equivalence have been shown to perform very well in simulation studies (Pokropek et al., 2019) and partial equivalence reflects well the situation in real life applications I which many of the items that make up an index are comparable and display full measurement invariance prosperities while a selected number of items are non-invariant (Davidov et al., 2014). In recent years, the concept of approximate measurement invariance (AMI) has also gained considerable attention (Asparouhov & Muthén, 2014). The AMI postulates that estimations of reliable and comparable parameters for different groups in multiple-group models is possible despite small "natural" differences between item parameters from different groups. A combination of AMI and partial invariance appears most promising when the objective is to develop comparable indicators across a large number of diverse groups: such combination allows to consider exact measurement invariance for some parameters, exact measurement non-invariance for some other parameters, and approximate measurement invariance for the remaining parameters.

As a result, we used confirmatory factor analysis (CFA) with alignment optimization (Asparouhov & Muthén, 2014; Muthén & Asparouhov, 2014; Pokropek, Lüdtke, and Robitzsch 2020) to construct measures of ICT use that satisfy partial approximate invariance. Alignment optimization replaces cross-country equality constraints with a procedure similar to rotation in Explanatory Factor Analysis (EFA). An iterative algorithm estimates a solution that minimizes overall differences between group parameters and adjusts factor means and variances. In the end the algorithm determines a solution that has a model fit that is equal to those obtained using the configural model but also guarantees the maximum level of comparability. Simulation studies showed that this method can successfully recover the group parameters even in the presence of a substantial number of non-invariant items when these are accompanied by small differences for the rest of the items (Asparouhov & Muthén, 2014; Pokropek 2019; Pokropek, Lüdtke, & Robitzsch 2020).

We tested the performance of alignment optimization models in the construction of PISA's ICT indicators using simulation studies. Simulations were performed according to guidelines developed by Asparouhov and Muthén (2014). In the first step we randomly generated 100 datasets that reflect the data structure in the estimation sample. For data generation we used the final parameters from fixed alignment estimation. In the second step, we used these data sets as input to estimate CFA with alignment optimization and construct each index of ICT use. For each of the 100 replications, we computed correlations between true group means and variances (used for generating the data) and estimated group means and variances. We also computed the mean square error (MSE) between true and estimated parameters. Correlations and MSEs were than averaged over replications. The correlation measure was promoted by Asparouhov and Muthen (2014) as a simple measure of reliability of latent means estimated using a specific method. Asparouhov and Muthen (2014) suggest that correlations larger than 0.98 indicate reliable rankings of groups. The mean square error (MSE) provides an overall measure of accuracy of the parameter estimation. Results of the simulations are presented in Table 1

Table 1
Correlations and Mean Square error of population and estimated values using CFA with alignment optimization

Variable		Correlations		Mean square error	
		Average	Std. Dev.	Average	Std. Dev.
ICT for leisure	Mean	0.9938	0.0009	0.0361	0.005
	Variance	0.9840	0.0010	0.0959	0.007
ICT for learning at home	Mean	0.9945	0.0008	0.0657	0.017
	Variance	0.9922	0.0010	0.0603	0.014
ICT for learning at school	Mean	0.9978	0.0003	0.2183	0.017
	Variance	0.9968	0.0004	0.0860	0.025

Results presented in Table 1 indicate high overall correlations between the values obtained with CFA with alignment optimization and values estimated from simulations of means and variances, and relatively low MSEs. This is an indication that the measurement model used to construct the indices guided by approximate measurement invariance assumptions provides reliable measures of indices of ICT use both in terms of cross-time and cross-country comparisons. As a result, Table 1 confirms the validity of comparisons.

Modelling relations between ICT and Reading Achievement

In order to estimate trends over time in ICT use we standardized all ICT use variables so that in 2009 the mean of each index would be zero and the standard deviation would be one on average across the countries in our sample. To investigate differences in trends in ICT use we compared mean levels between boys and girls and between students with and students without at least tertiary educated parent. To estimate the association between different forms of ICT and reading achievement we fitted a series of regression models on the pooled sample of 28 countries and included country fixed effects in which reading achievement, standardized to have a mean of zero and a standard deviation of one across countries in 2009 was regressed on each indicator of ICT use, gender and parental educational attainment.

Regression models considered the PISA complex sampling design through balanced Taylor linearization (Demnati & Rao; 2004). Furthermore, because reading achievement is expressed in terms of plausible values (Mislevy, Beaton, Kaplan, & Sheehan, 1992) all estimates were conducted using multiple imputation methodology. This involved fitting five sets of models, each with one plausible value, and then combining these values using the Rubin rule (Little & Rubin, 1987) as per OECD recommendations (OECD, 2007b). We employed linear regression with three-degree polynomials to capture nonlinear relations and used marginal effects to depict the relations between ICT indices and reading abilities (Williams 2012).

In order to quantify differences between ICT and reading competencies in an easily interpretable way, we fitted piecewise regressions (McZgee & Carleton 1970). Piecewise regression allowed us to specify different intercepts and different linear slopes for values of each ICT index below/above zero. For each indicator of ICT use four piecewise regressions models are presented. In model 1 estimates describe associations controlling for background characteristics (gender and parental education), country fixed effects and year fixed effects. In model 2 controls for additional forms of ICT use were added. In model 3 interactions between indicators of ICT use and the year in which the survey took place were added (but not other forms of ICT use) and in model 4 all controls were added.

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<div align="center">**Results**</div>

The evolution of ICT use

Figure 1 illustrates changes between 2009 and 2018 in levels of ICT use as well as changes in PISA reading scores over the same period among 15-year-old students in OECD countries. Although PISA reading scores remain flat over the period, ICT use increased markedly over time, and the rate of such increase differed depending on the type of ICT use considered. More specifically, the increase in the use of ICT for leisure was small when compared to the steep increase in the use of ICT for school occurring in the home setting and in school settings. In 2009 the value of the index of ICT use for leisure was fixed to mean 0 points by 2018 it had grown by 39% of a standard deviation. By contrast, the value of the ICT use for learning at home index grew by 75% of a standard deviation between 2009 and 2018, and the mean value of the ICT use for learning at school index grew by 71% of a standard deviation in the same period. The different patterns could reflect, in part, the fact that ICT was already highly used for leisure in 2009 and therefore there was less room for marked increases given students' overall time availability. In any case they indicate that the use of ICT for academic purposes whether in school settings or at home was already increasing rapidly before the COVID-19 pandemic hit in 2020.

Figure 1
Trends in levels of ICT use and reading achievement between 2009 and 2018, OECD average
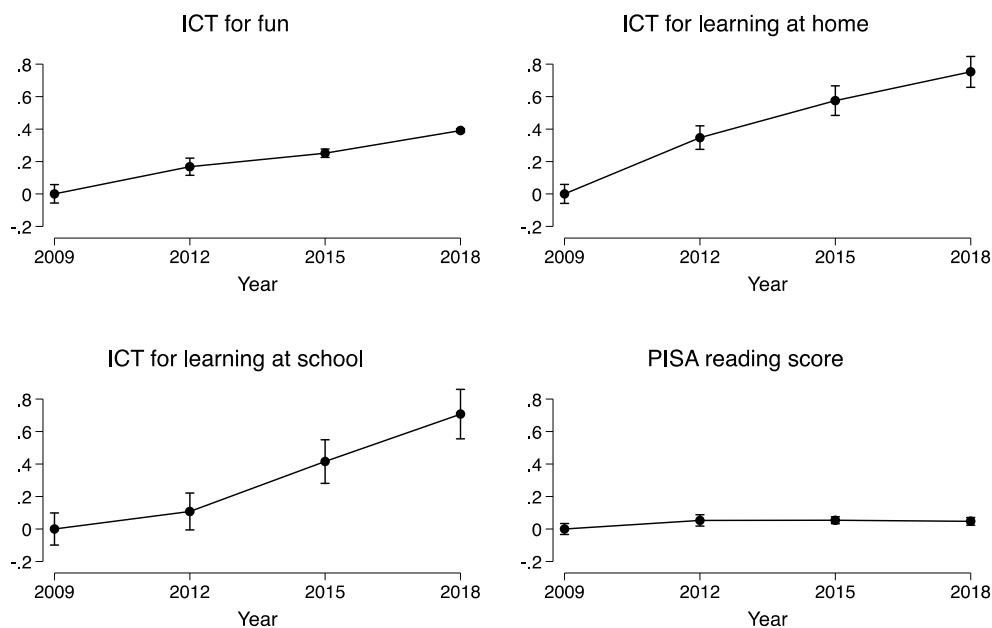
Heterogeneity in the evolution of ICT use

In line with the literature on gender differences in reading achievement and the literature on socio-economic disparities in academic achievement, Figures 2 and 3 indicate that girls outperform boys in reading (on average by 41% of a standard deviation) and that children with tertiary educated parents outperform children with no parent who achieved tertiary level qualifications (on average by 43% of a standard deviation). Furthermore, results presented suggest that gender differences in favor of girls narrowed over the period and so did differences by parental educational attainment.

Figure 2 further reveals that boys are more likely to use ICT than girls, particularly for leisure and for learning at school and that gender differences in all uses of ICT widened between 2009 and 2018, although among girls between 2015 and 2018 the increase in ICT use for leisure became more pronounced approaching rates of increase observed among boys. As a result, the gender gap in the use of ICT for leisure increased from 16% of a standard deviation in 2009 to 28% of a standard deviation in 2012, 47% of a standard deviation in 2015 and 43% of a standard deviation in 2018. Increases in the use of ICT for learning at home was similar among boys and girls in 2009, it increased in a similar way among both boys and girls between 2009 and 2012 but after 2012 the increase among boys outpaced that observed among girls. As a result, the gender gap in ICT use for learning at home changed from 2% of a standard deviation in favor of boys in 2009, 2% of a standard deviation in favor of girls in 2012; 12% of a standard deviation in favor of boys in 2015 and 17% of a standard deviation in favor of boys in 2018. A similar pattern can be observed with respect to the use of ICT for learning at school: gender differences were small and imprecisely estimated in 2009 and 2012, but after 2012 the use of ICT for learning at school increased markedly, especially among boys. The gender gap in ICT used for learning at school changed from 17% of a standard deviation in 2009, 20% of a standard deviation in 2012, 31% of a standard deviation in 2015 and 35% of a standard deviation in 2018. By contrast, Figure 3 suggests that differences in trends in ICT use among 15-year-old students with tertiary and without tertiary educated parents differed little.

Figure 2
Trends in levels of ICT use and reading achievement between 2009 and 2018 among boys and girls, OECD average
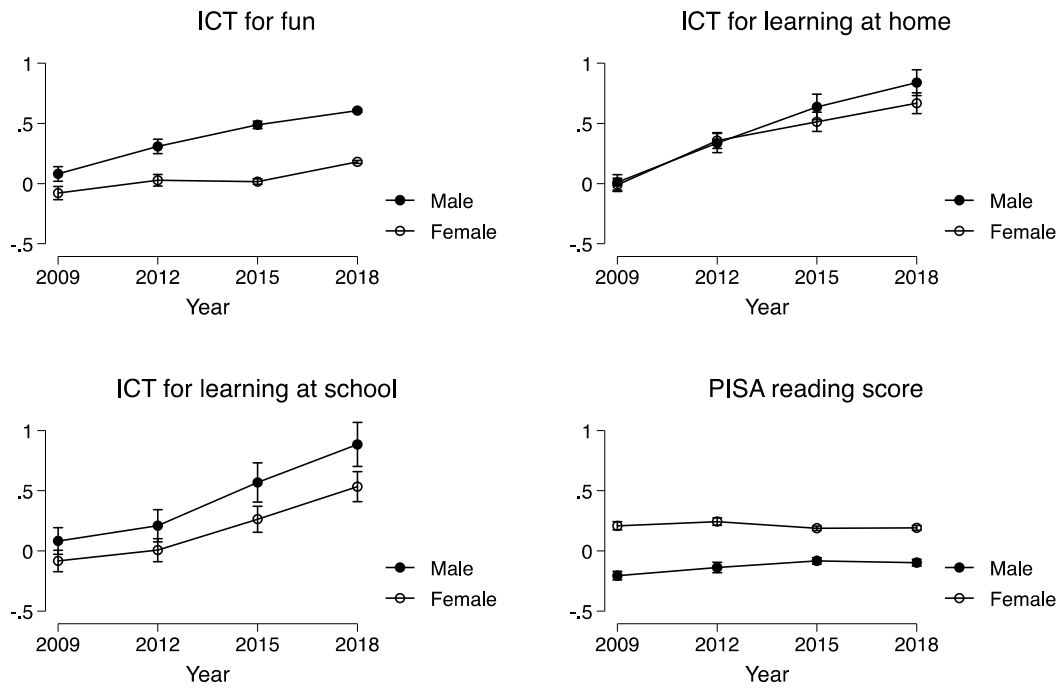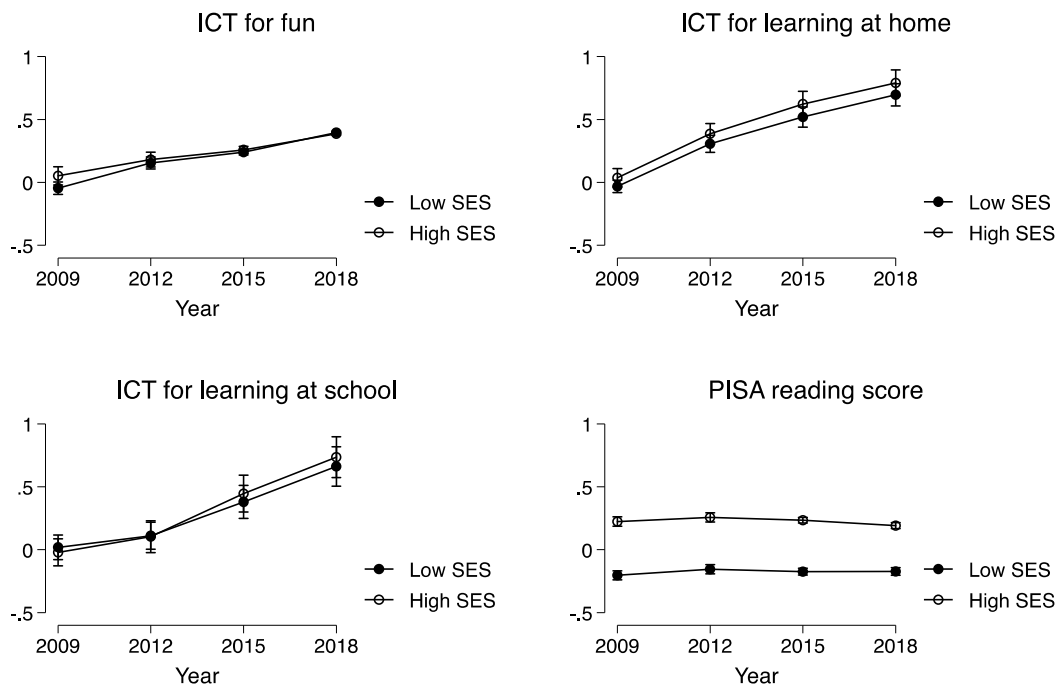

Figure 3
Trends in levels of ICT use and reading achievement between 2009 and 2018 among 15-year-olds with and without tertiary educated parents, OECD average


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Figures 4, 5, 6 and 7 indicate that between 2009 and 2018 there were marked changes not just in the average levels of reading achievement and ICT use but especially in the distributions of reading achievement and ICT use in the population of 15-year-old students. On average, reading achievement changed little over the period. However, especially since 2015, the distribution became considerably flatter and the standard deviation increased as fewer students had levels of performance that were closer to the average and a larger number of students had achievement scores that were either very much below or very much above the average.

In 2009 the distribution of students' use of ICT for leisure was left skewed but with a sizable number of students displaying very low and low levels of use, and many students reporting high levels of use. The increase in average levels of use of ICT for leisure that occurred between 2009 and 2018 was due to a remarkable change in the distribution of use over the period: by 2018 almost no student reported very low levels of use and the vast majority of students reported levels of use that were just below or well above the average use observed in 2009.

By contrast, the distributions of use of ICT for learning either at home or at school were right-skewed in 2009. The use of ICT for learning at school had an especially skewed distribution with many students reporting very low levels of use in 2009 and while it remained skewed, a larger number of students reported higher levels of use by 2018. By contrast, use of ICT for learning at home by 2018 had acquired a rather symmetric, unimodal distribution, with many children reporting average levels and some reporting either high or low levels of use.

Figure 4
Trends in the distribution of the use of ICT for leisure between 2009 and 2018
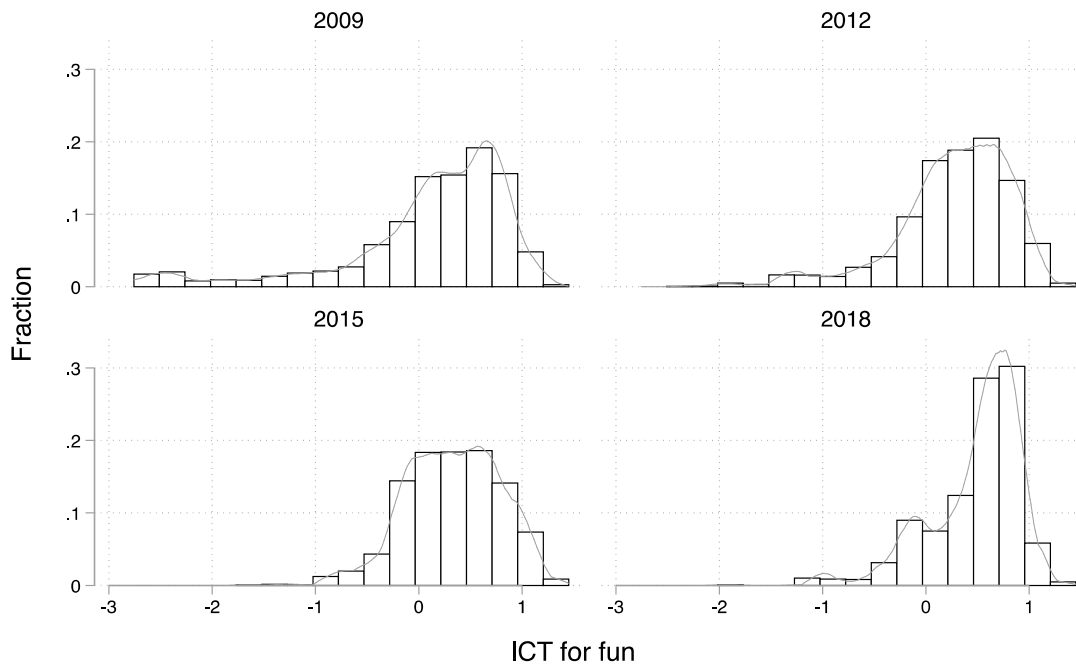
Graphs by Year

Figure 5
Trends in the distribution of the use of ICT for learning at home between 2009 and 2018
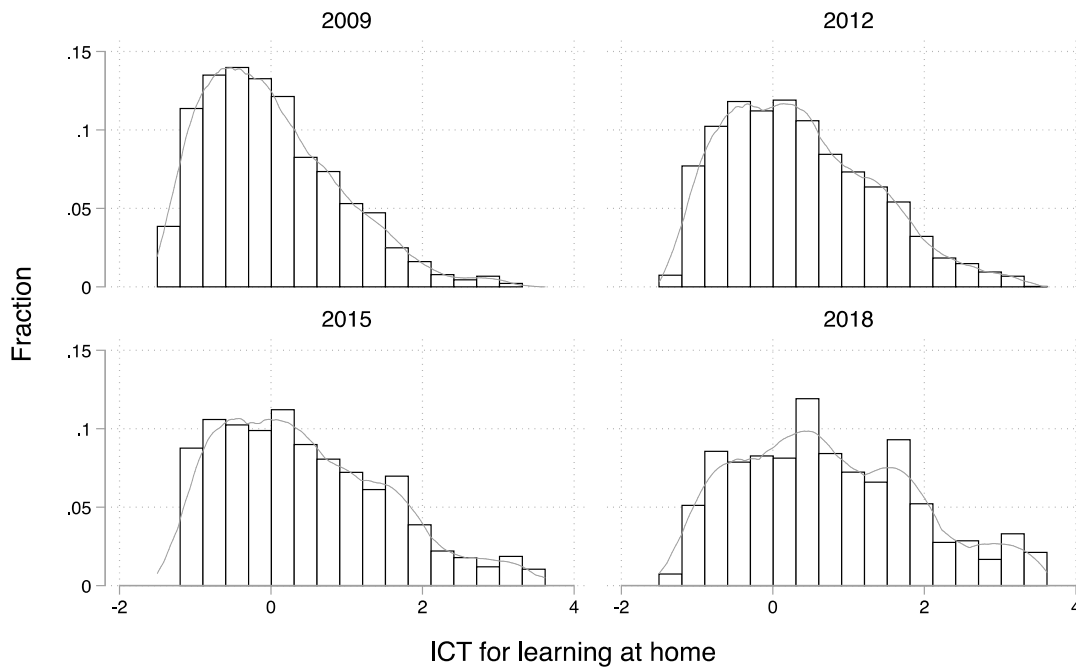
Graphs by Year

Figure 6
Trends in the distribution of the use of ICT for learning at school between 2009 and 2018
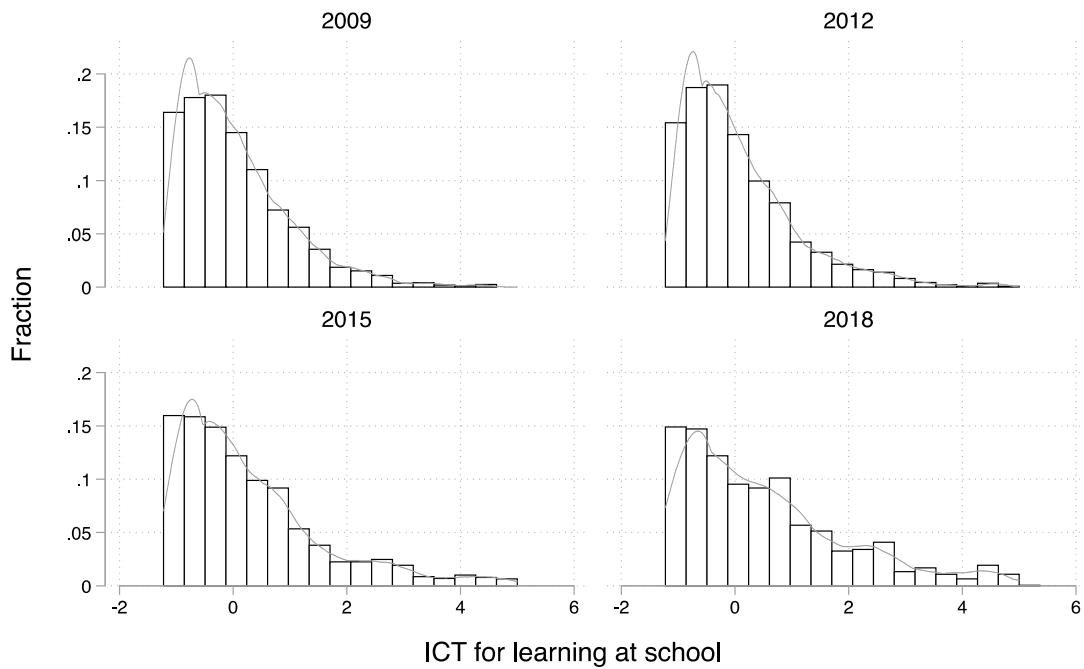
Figure 7
Trends in the distribution of the use of reading scores between 2009 and 2018
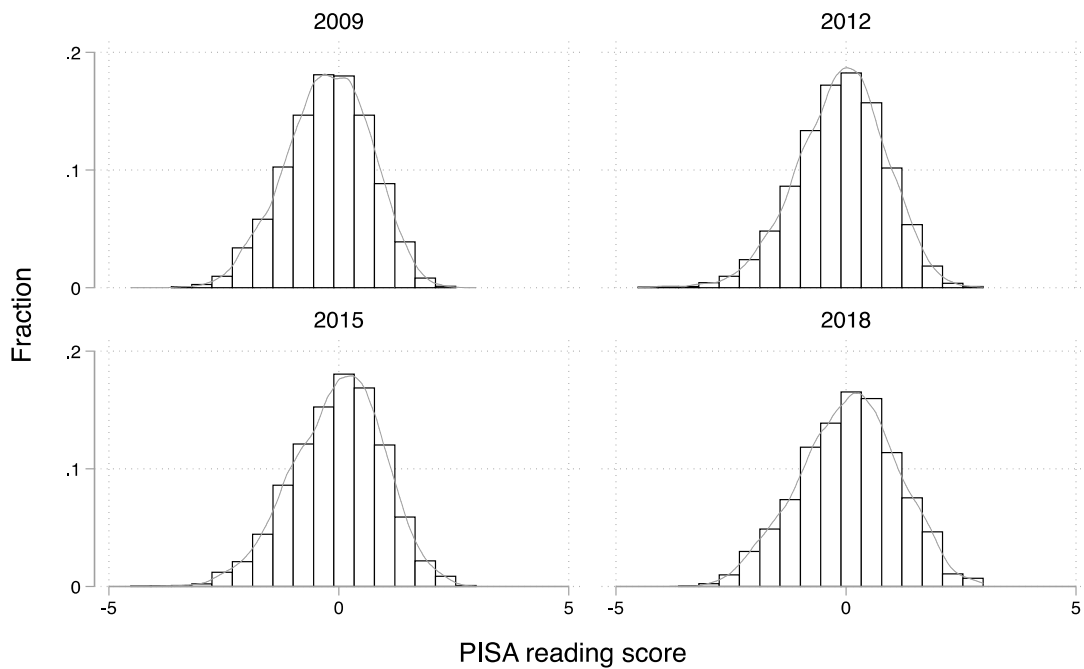
The evolution of the association between ICT use and reading achievement

Table 2 details changes between 2009 and 2018 in the average association between different forms of ICT use and reading achievement. Results suggest that the association between ICT

use for leisure and reading achievement was low throughout the period, ranging from the small positive in 2009 to the small negative in 2018. By contrast, on average students making greater use of ICT for school purposes at home or at school generally had lower reading achievement than students making less use. The strongest negative association was between ICT use for learning purposes at school and reading achievement and the association remained relatively stable over the period ranging from $r = -.196$ in 2009 to $r=-.237$ in 2018. By contrast, the association between ICT use for school at home grew progressively more negative over time: in 2009 $r = -.013$ and in 2018 $r = -.144$. The use of ICT for leisure was positively but weakly associated with the use of ICT for learning both at home and at school throughout the period. The association between the use of ICT for learning at home and using it at school was positive and grew stronger over the period: it was $r = .410$ in 2009 and $r = .569$ in 2018.

Table 2
Trends in the association between ICT use and reading achievement Pearson correlations

Year	Associations between reading and:			Association between ICT use at home and:	Association between ICT use at home and:	Association between ICT use for fun and:
	ICT for fun	ICT for learning at home	ICT for learning at school	ICT for fun	ICT use at home school	ICT use at home school
2009	0.021	-0.013	-0.196	0.345	0.410	0.127
2012	-0.007	0.010	-0.189	0.227	0.457	0.166
2015	-0.047	-0.090	-0.206	0.237	0.558	0.222
2018	-0.018	-0.144	-0.237	0.225	0.569	0.192

Figure 8 considers potential non linearities in the associations between reading achievement and different forms of ICT. Figure 8 indicates that the association between ICT use for leisure and reading achievement is well represented by an inverted U shape and that the inverted U shape became steeper at low levels of ICT use over time. Moreover, relations shifted to the right over the period, reflecting increasing use. In 2009, 15-year-olds who used little ICT for leisure had the lowest levels of reading achievement. Achievement was higher among students with higher levels of use, but there were only small differences in achievement between students who differed little in ICT use. Achievement was highest among students with average levels of ICT use. Beyond such threshold, increasing levels of ICT use for leisure were associated with increasingly lower levels of achievements. Starting in 2012, fewer students reported low levels of use, a trend that became more pronounced over time. Moreover, students with very low levels of ICT use for leisure over time had lower levels of

achievement than students with comparable levels of use in 2009. From 2012 onwards, at low levels of use, achievement started to be markedly higher among students with higher levels of use. In all four PISA surveys students with the highest levels of reading achievement were students that used ICT for leisure in line with the average levels of use that were observed in 2009.

Figure 8
Trends in the association between reading achievement and the use of ICT
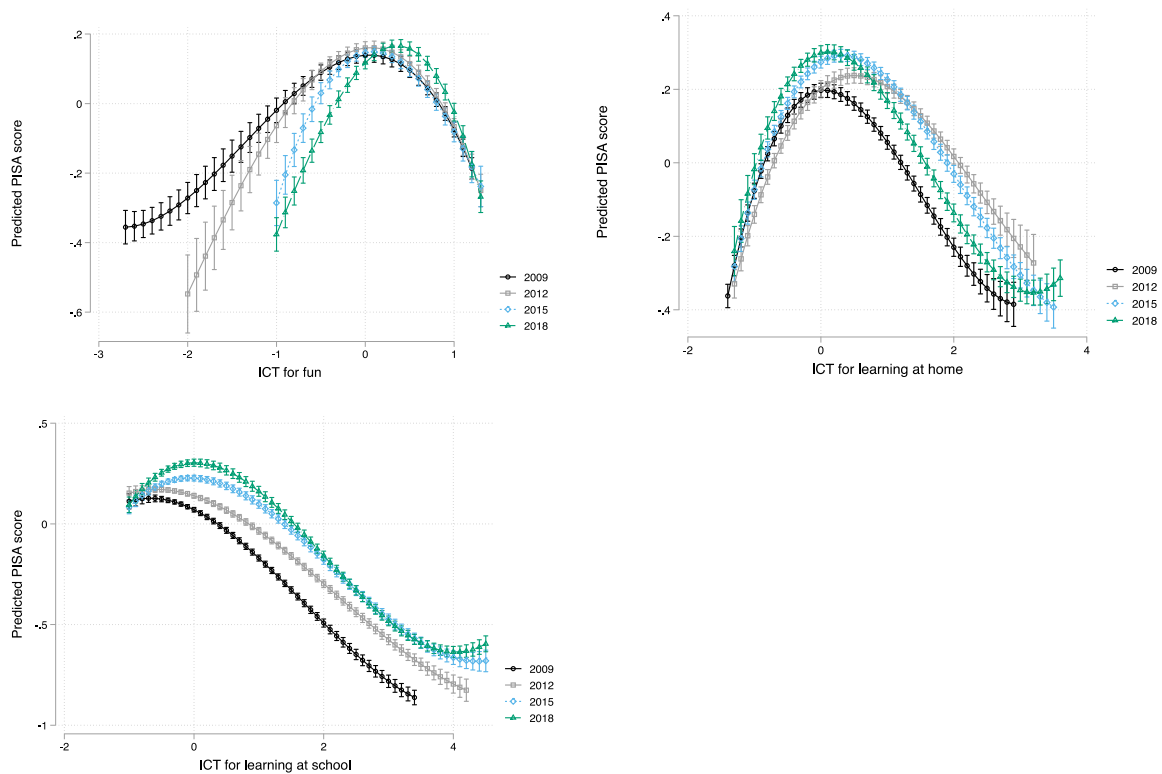
The association between ICT use for learning at home can also be described by an inverted U shape: the highest achieving students are students with levels of use that are aligned with the levels of use observed on average across OECD countries in 2009. Moreover, the positive change in reading achievement that is associated with levels of use below the average is greater than the negative change in reading achievement that is associated with levels of use above the average. Between 2009 and 2018 associations became steeper at low levels of use, although there is evidence of a second inflection point at very high levels of use of ICT for learning at home. Interestingly, Figure 6 indicates that the association between ICT use for learning at school is broadly negative given levels of use observed between 2009 and 2018,

although between 2009 and 2018 students with the lowest levels of use increasingly lagged behind in terms of reading achievement when compared to students with low levels of use.\

Differences in the evolution of the association between ICT use and reading achievement

Results presented in Figure 8 clearly indicate that the association between ICT use and reading achievement differs according to the level of ICT use. Such figures also suggest that levels of use observed on average across students in OECD countries in 2009 broadly correspond to the peak of the inverted U that describes the association between ICT use and reading achievement. Tables 3, 4 and 5 more formally describe the association between each indicator of ICT use and reading achievement while controlling for background characteristics such as gender and parental educational attainment, how associations changed over time and how results are affected by the inclusion of additional controls characterizing other forms of ICT use.

Results describing the association between ICT use for leisure and reading achievement in Table 3 indicate that over the 2009-2018 period, the use of ICT for leisure was positively associated with reading achievement at low levels of use and negatively associated with reading achievement at high levels of use (model 1 results). Controlling for other forms of ICT use in model 2 halved the estimated positive association at low levels of use and pointed to a lack of association over the period at high levels of use. However, models 3 and 4 indicate that associations changed markedly over the period. At levels of use lower than 0 in 2009, when controlling for all factors in model 4, increases in use of ICT for leisure were associated with a positive difference of 8% of a SD in reading achievement. By 2018 this difference grew considerably and stood at 44% of a SD. At levels of use above 0 in 2009, when controlling for all factors in model 4, increases in use of ICT for leisure were associated with a negative difference of 12% of a SD in reading achievement. By 2018 this difference was no longer negative and, in fact, increases at high levels of use were associated with a positive difference in reading achievement. By 2018, a change of one SD in ICT use for leisure at high levels of use was associated with a positive change of around 10% of a SD in reading achievement.

Table 3

Regression results describing changes in the association between ICT use for leisure and reading achievement between 2009 and 2018

	(1)	(2)	(3)	(4)
Intercept <0	-0.175***	0.0397*	-0.139***	0.0917***
	(0.0208)	(0.0191)	(0.0210)	(0.0191)
Intercept >=0	-0.120***	0.0946***	-0.123***	0.102***
	(0.0207)	(0.0186)	(0.0208)	(0.0186)
ICT for fun (<0)	0.161***	0.0833***	0.154***	0.0805***
	(0.0101)	(0.0108)	(0.00997)	(0.0106)
ICT for fun (>-=0)	-0.0935***	0.000766	-0.172***	-0.117***
	(0.00886)	(0.00775)	(0.0145)	(0.0135)
female	0.349***	0.303***	0.357***	0.315***
	(0.00493)	(0.00482)	(0.00494)	(0.00485)
SES	0.405***	0.394***	0.404***	0.393***
	(0.00420)	(0.00424)	(0.00419)	(0.00422)
Year 2012	0.000128	0.0157	0.00337	0.0169
	(0.0125)	(0.0121)	(0.0132)	(0.0120)
Year 2015	-0.0305**	0.0497***	-0.0501***	0.00320
	(0.0118)	(0.0104)	(0.0129)	(0.0117)
Year 2018	-0.0688***	0.0561***	-0.101***	-0.00761
	(0.0130)	(0.0130)	(0.0141)	(0.0129)
ICT Home		0.107***		0.109***
		(0.00431)		(0.00414)
ICT Home^2		-0.125***		-0.125***
		(0.00469)		(0.00437)
ICT Home^3		0.0227***		0.0219***
		(0.00134)		(0.00124)
ICT School		-0.112***		-0.115***
		(0.00725)		(0.00706)
ICT school^2		-0.0783***		-0.0752***
		(0.00582)		(0.00562)
ICT School^3		0.0150***		0.0143***
		(0.00113)		(0.00110)
Year 2012# ICT for fun (<0)			0.0882*	0.122**
			(0.0349)	(0.0374)
Year 2015# ICT for fun (<0)			0.239***	0.263***
			(0.0331)	(0.0359)
Year 2018# ICT for fun (<0)			0.363***	0.361***
			(0.0315)	(0.0283)
Year 2012# ICT for fun (>=0)			0.0398*	0.0594***
			(0.0188)	(0.0164)
Year 2015# ICT for fun (>=0)			0.123***	0.204***
			(0.0211)	(0.0168)
Year 2018# ICT for fun (>=0)			0.152***	0.232***
			(0.0206)	(0.0175)
Country Fixed effects	YES	YES	YES	YES
N	645410	642240	645410	642240
adj. R^2	0.1314	0.1821	0.1342	0.1863

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimates presented in model 1 of Table 4 suggest that on average, over the 2009-2018 period, the use ICT for learning at school was positively associated with reading achievement at levels of use higher than 0: a change of one SD in ICT for learning at school was associated with a positive difference of 14% of a SD in reading achievement for levels of use greater than 0. However, the use ICT for learning at school was negatively associated with reading achievement at levels of use lower than 0: a change of one SD in ICT for learning at school was associated with a positive difference of 19.5% of a SD in reading achievement for levels of use lower than 0. Controlling for other forms of ICT halved the strength of the association observed for values of use of ICT for learning at school higher than 0. Models 3 and 4 indicate that also in the case of use of ICT for learning at school relations changed over time. In particular, the association between the use of ICT for learning at school and reading achievement became positive at low levels of use only starting in 2015 and the negative association observed at high levels of use became slightly less negative over time.

Table 4

Regression results describing changes in the association between ICT use for learning at school and reading achievement between 2009 and 2018

	(1)	(2)	(3)	(4)
Intercept <0	0.0144	0.132***	-0.00460	0.121***
	(0.0198)	(0.0196)	(0.0203)	(0.0201)
Intercept >=0	-0.0634**	0.0427*	-0.0773***	0.0404*
	(0.0193)	(0.0183)	(0.0193)	(0.0189)
ICT for school (<0)	0.140***	0.0634**	0.0405	-0.0382
	(0.0197)	(0.0198)	(0.0323)	(0.0315)
ICT for school (>-=0)	-0.195***	-0.179***	-0.234***	-0.239***
	(0.00440)	(0.00453)	(0.00640)	(0.00664)
female	0.303***	0.302***	0.300***	0.300***
	(0.00452)	(0.00481)	(0.00452)	(0.00466)
SES	0.414***	0.394***	0.412***	0.391***
	(0.00417)	(0.00423)	(0.00414)	(0.00416)
Year 2012	0.0586***	0.0154	0.0495***	-0.00168
	(0.0119)	(0.0124)	(0.0116)	(0.0119)
Year 2015	0.0866***	0.0455***	0.139***	0.0854***
	(0.0110)	(0.0105)	(0.0117)	(0.0119)
Year 2018	0.100***	0.0516***	0.184***	0.125***
	(0.0135)	(0.0131)	(0.0142)	(0.0147)
ICT Home		0.0992***		0.0979***
		(0.00449)		(0.00450)
ICT Home^2		-0.133***		-0.132***
		(0.00462)		(0.00428)
ICT Home^3		0.0268***		0.0263***
		(0.00141)		(0.00129)
ICT Fun		0.114***		0.122***
		(0.0130)		(0.0112)
ICT Fun^2		-0.0536***		-0.0577***
		(0.00744)		(0.00667)
ICT Fun^3		-0.0278***		-0.0293***
		(0.00440)		(0.00394)
Year 2012# ICT for school (<0)			0.00182	0.00181
			(0.0412)	(0.0423)
Year 2015# ICT for school (<0)			0.196***	0.197***
			(0.0362)	(0.0341)
Year 2018# ICT for school (<0)			0.277***	0.288***
			(0.0422)	(0.0438)
Year 2012# ICT for school (>=0)			0.0294***	0.0477***
			(0.00809)	(0.00818)
Year 2015# ICT for school (>=0)			0.0412***	0.0676***
			(0.00894)	(0.00875)
Year 2018# ICT for school (>=0)			0.0298**	0.0550***
			(0.00965)	(0.00948)
Country fixed effects	YES	YES	YES	YES
N	648859	642240	648859	642240
adj. R^2	0.1678	0.1821	0.1705	0.1855

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Finally, Table 5 reports results for the association between the use of ICT for learning at home and reading achievement. In line with results presented in Tables 3 and 4, findings reported in Table 5 suggests that the association between ICT use for learning at home and reading achievement became more positive at low levels of use over time, and that the association between ICT use for learning at home and reading achievement became less negative at high levels of use over time.

Table 5

Regression results describing changes in the association between ICT use for learning at home and reading achievement between 2009 and 2018

	(1)	(2)	(3)	(4)
Intercept <0	0.0528**	0.166***	0.0438*	0.151***
	(0.0196)	(0.0196)	(0.0199)	(0.0199)
Intercept >=0	-0.0393*	0.0800***	-0.0599**	0.0600**
	(0.0186)	(0.0184)	(0.0190)	(0.0189)
ICT home(<0)	0.387***	0.367***	0.332***	0.256***
	(0.0112)	(0.0115)	(0.0154)	(0.0168)
ICT home(>-=0)	-0.164***	-0.0510***	-0.182***	-0.0989***
	(0.00403)	(0.00402)	(0.00827)	(0.00868)
female	0.323***	0.301***	0.321***	0.302***
	(0.00465)	(0.00478)	(0.00463)	(0.00471)
SES	0.407***	0.394***	0.407***	0.394***
	(0.00425)	(0.00423)	(0.00424)	(0.00417)
Year 2012	0.0387***	0.0172	0.0229	0.0181
	(0.0116)	(0.0123)	(0.0158)	(0.0158)
Year 2015	0.0515***	0.0454***	0.0932***	0.0910***
	(0.0108)	(0.0104)	(0.0136)	(0.0127)
Year 2018	0.0316**	0.0536***	0.0926***	0.119***
	(0.0119)	(0.0131)	(0.0144)	(0.0133)
ICT Home		-0.109***		-0.113***
		(0.00723)		(0.00707)
ICT Home^2		-0.0803***		-0.0784***
		(0.00587)		(0.00566)
ICT Home^3		0.0151***		0.0148***
		(0.00116)		(0.00114)
ICT School		0.115***		0.122***
		(0.0130)		(0.0117)
ICT school^2		-0.0606***		-0.0648***
		(0.00739)		(0.00701)
ICT School^3		-0.0299***		-0.0264***
		(0.00441)		(0.00407)
Year 2012# ICT home(<0)			0.0452	0.0923**
			(0.0295)	(0.0311)
Year 2015# ICT home(<0)			0.142***	0.224***
			(0.0208)	(0.0201)
Year 2018# ICT home(<0)			0.137***	0.255***
			(0.0256)	(0.0256)
Year 2012# ICT home(>=0)			0.0647***	0.0692***
			(0.0109)	(0.0109)
Year 2015# ICT home (>=0)			0.0137	0.0485***
			(0.0103)	(0.0102)
Year 2018# ICT home(>=0)			-0.00818	0.0321**
			(0.00971)	(0.0103)
Country fixed effects	YES	YES	YES	YES
N	643704	642240	643704	642240
adj. R^2	0.1490	0.1818	0.1501	0.1842

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Limitations

Our study suffers from a number of limitations that could be addressed in future research. First, the repeated cross-sectional dimension of the study means that results cannot be interpreted causally. Second, our indicators of ICT use identify quantitative dimensions (such as how frequently and how many different activities children engaged in) rather than qualitative dimensions (such as content of ICT use). Third, findings refer to text comprehension skills and may therefore not apply in the same way to other domains, such as mathematics and science. Finally, although our work considers relationships across a large number of countries over almost a decade, they cannot necessarily be generalized to other context, whether temporal or geographic.

Discussion

The ubiquitous presence of information and communication technology (ICT) in children's lives has been a growing concern amongst educators, politicians, and parents for decades (Orben, 2020). Such concerns increased during the COVID-19 pandemic: face-to-face schooling was interrupted and remote learning through ICT technologies became widespread (Dwivedi, 2020). In the spring of 2020, an Internet connection and a mobile device replaced the classroom in the space of a day for hundreds of millions of students worldwide (UNESCO, 2021). An increasing number of studies examine the effects of school closures due to Covid-19 on students' learning progress (Engzell, Frey & Verhagen, 2021; UNESCO, 2021; OECD, 2021) and the effectiveness of remote learning to substitute face-to-face learning has been questioned in this context as not being effective (Reich, 2020; Thompson, 2013; UNESCO, 2021).

The evidence presented suggests that already before the pandemic, whether in school or at home, students had increased their use of ICT for learning. By developing indicators of ICT use that are comparable across countries and over time, we show that the use of ICT for learning at school and at home increased by around three quarters of a standard deviation between 2009 and 2018. As a potential reflection of the greater use of ICT at school, the PISA test changed mode of administration between 2012 and 2015: until 2012 it was delivered in paper booklets while from 2015 it became computer based. Increases in the use of ICT for leisure were large but not as pronounced (41% of a standard deviation), a possible reflection of the fact that teenagers already used ICT for leisure to a much higher degree in 2009. Gender gaps became more pronounced over the period, with boys consuming more

ICT for learning and for leisure than girls, while we did not observe socio-economic disparities in the use of ICT in any of the years under examination. In line with the previous literature, we identify an inverted U-shaped association between different forms of ICT use and reading achievement and that in 2009, the association between ICT for learning at school and reading achievement was decreasing over the observed distribution of use. At the population level, the association between the use of ICT and reading achievement became more negative over time. However, this change was a reflection of the increase in ICT use among boys, who generally have lower levels of achievement. Over time, associations between different forms of ICT use and reading achievement grew more positive at low levels and less negative at high levels. Because ICT use increased markedly over the period, and therefore more students were located in the decreasing section of the association, overall levels of achievement remained relatively stable despite large increases in ICT use.

Our study suggests that as the use of ICT becomes pervasive and familiarity with ICT becomes important to be able to take part in computer-administered tests, students who have very low levels of use are increasingly penalized and display lower reading achievement than students with moderate levels of use. At the same time, high levels of use remain associated with lower achievement than moderate levels of use, even when the use of ICT is widespread and ICT is integrated in testing. At high levels of use, any gains in reading achievement that are associated with greater familiarity with ICT are more than compensated by displacement effects of activities that would be more conducive to reading proficiency, such as, for example, practicing reading. Table A1 in the Annex suggests that between 2009 and 2018, just as the use of ICT increased, there was a sizable increase in the number of students who considered reading a waste of time or who reported reading only if they had to.

Results presented indicate that ensuring that all students have access to and are familiar with a broad array of ICT devices may be increasingly important to ensure that they are able to demonstrate their skills effectively. As many activities occur through technology, the ability to effectively operate ICT moderates children's expression of what they know and can do. However, familiarity with ICT devices can be achieved through levels of use that are considerably lower than the levels of use of an increasing number of teenagers. In particular, until 2018 ICT use for learning at home and especially at school, appears to have been associated with lower overall reading achievement beyond very low levels of use. Although our results cannot be interpreted causally, they suggest that before the pandemic, students displayed greater proficiency when their teachers only used ICT in the classroom for certain activities. The fact that the use of ICT for learning, whether in school or at home, increased

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the most among groups of students that are generally more difficult to motivate with learning, such as boys, suggests that until 2018 the use of ICT for learning was used by educators as a way to build engagement and motivation. However, despite potential motivational benefits and potential improvements in the quality of ICT resources used in classrooms and in teachers' ability to effectively use ICT in the classroom, our study suggests that when ICT is used extensively for learning, text comprehension skills tend to be lower.

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Table A1
Trends in reading activities between 2009 and 2018

		Year	Proportion	95% CI	
I read only if I have to.	Strongly	2009	20.8%	20.5%	21.1%
	disagree	2018	20.9%	20.6%	21.2%
	Disagree	2009	36.5%	36.2%	36.9%
		2018	30.9%	30.6%	31.2%
	Agree	2009	30.6%	30.3%	30.9%
		2018	30.6%	30.3%	30.9%
	Strongly Agree	2009	12.1%	11.9%	12.3%
		2018	17.6%	17.4%	17.9%
For me. reading is a waste of time	Strongly	2009	36.1%	35.7%	36.5%
	disagree	2018	33.5%	33.1%	33.8%
	Disagree	2009	40.9%	40.6%	41.3%
		2018	39.2%	38.9%	39.5%
	Agree	2009	14.7%	14.4%	14.9%
		2018	17.1%	16.9%	17.4%
	Strongly Agree	2009	8.3%	8.1%	8.5%
		2018	10.2%	10.0%	10.4%

Source: PISA 2009 and 2018 datasets. Results on pooled data across 28 countries.