# The Impact of Digital Device Usage on Educational Achievement: Evidence from PISA Data

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Dissertation written under the supervision of Professor Hugo Reis

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**Abstract**

Our study explores the relationship between digital device usage and educational achievement, aiming to bring clarity to the mixed findings from previous literature on this topic. By analyzing data from the OECD's Programme for International Student Assessment (PISA) 2009 and 2018 editions, we investigate how digital device usage during and outside classroom lessons impacts educational achievement across three subjects. Our methodology is based on a similar approach used by Falck et al. (2018), using a Correlated Random Effects model (CRE) estimated through Seemingly Unrelated Regressions (SUR). This model allows us to exploit the within-student between-subject variation to control for unobserved student characteristics. Our findings suggest a subject-specific effect, meaning that the impact varies across subjects and whether digital device usage occurs during classroom or outside classroom lessons. We find evidence indicating that not using digital devices incurs a penalty for students, suggesting that the impact of digital device usage depends more on its presence than the amount of time spent using them. Additionally, our results suggest that digital devices can provide additional support to students from disadvantaged backgrounds or those with lower academic performance.

**Keywords**: PISA, Information and Communication Technologies (ICT), Correlated Random Effects Model, Seemingly Unrelated Regression, Educational Achievements

# O impacto da utilização de dispositivos digitais no sucesso escolar: Evidências dos dados do PISA

Lykke Nyberg

**Resumo**

O nosso estudo explora a relação entre a utilização de dispositivos digitais e o sucesso escolar, com o objetivo de clarificar as conclusões contraditórias da literatura anterior sobre este tema. Analisando dados das edições de 2009 e 2018 do Programa Internacional de Avaliação de Estudantes (PISA) da OCDE, investigamos como a utilização de dispositivos digitais durante e fora das aulas tem impacto no sucesso escolar em três disciplinas. A nossa metodologia baseia-se numa abordagem semelhante à utilizada por Falck et al. (2018), utilizando um modelo de Efeitos Aleatórios Correlacionados (CRE) estimado através de Regressões Aparentemente Não Relacionadas (SUR). Este modelo permite-nos explorar a variação entre disciplinas do mesmo aluno para controlar as características não observadas do aluno. Os nossos resultados sugerem um efeito específico da disciplina, o que significa que o impacto varia consoante as disciplinas e se a utilização de dispositivos digitais ocorre durante as aulas ou fora delas. Encontrámos provas que indicam que a não utilização de dispositivos digitais implica uma penalização para os alunos, o que sugere que o impacto da utilização de dispositivos digitais depende mais da sua presença do que da quantidade de tempo passado a utilizá-los. Além disso, os nossos resultados sugerem que os dispositivos digitais podem proporcionar um apoio adicional aos alunos de meios desfavorecidos ou aos que têm um desempenho académico inferior.

Palavras-chave: PISA, Tecnologias de Informação e Comunicação (TIC), Efeitos Aleatórios Correlacionados (CRE), Regressão Aparentemente Não-Relacionadas (SUR), Sucesso escolar

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## 1. Introduction

The advent of Information and Communication Technology (ICT) has introduced new dynamics into the educational landscape, both within and outside the classroom. However, the impact of ICT on educational achievements, whether at school or at home, has yielded mixed findings in the existing literature (Bulman and Fairlie, 2016). While some studies suggest that ICT may significantly reduce educational disparities by giving students better learning chances, other research highlights the continued existence of inequalities regarding access and usage of technology (Claro et al., 2015).

Finding policies and practices that function consistently across various settings continues to be a difficult challenge. Given the complexity of educational inequality, exacerbated by the digital divide and the evolving role of ICT in modern education, there is a need for adaptive and context-specific solutions. Regarding these policy discussions, the COVID-19 pandemic highlighted the challenges and opportunities associated with the digital transition in today's society. It expedited the ongoing trend towards digital learning and prompted initiatives like the European Commission's Digital Education Action Plan (2021–2027), a policy aimed at promoting the development of digital education and increasing the level of digital literacy (Digital Learning and ICT in Education, 2023).

In recent research by Agostinelli et al. (2022), the authors shed light on the increased educational inequalities during the shift to virtual schooling due to the COVID-19 pandemic. Students from disadvantaged backgrounds face hurdles in virtual learning, experiencing a lack of positive peer interactions and parental support due to limited opportunities for remote work. Consequently, these factors contribute to a widening of learning gaps among students during the pandemic (Bacher-Hicks et al., 2021). Additionally, high achievers from low socioeconomic backgrounds seemed to be more impacted by this shift to virtual learning than other high achievers (Grewenig et al., 2021). Possible factors include students losing support from schools and teachers, which is used to lessen the impact of students' family backgrounds. Notably, countries that integrated ICT into their educational systems early on appeared better equipped to navigate these challenges (Directorate-General for Education et al., 2023).

These findings from the COVID-19 pandemic underscore the need for a deeper understanding of ICT's impact on educational achievement, especially since previous studies have yielded inconclusive results. However, considering the complexity of this topic, it is necessary to assess the relationship between ICT and education before the shock and determine whether these challenges existed before the pandemic. This study seeks to understand the impact of ICT on educational achievement, particularly in the context of how digital devices like tablets and computers affect educational achievement during classroom lessons as well as outside the classroom lessons (either at home or school). By answering the following research questions, we hope to come a step closer to understanding the evolving role of ICT in education, particularly its impact on student achievement:

a) How do digital devices impact test scores, and is there a significant difference between subjects? How has this impact changed in the decade before the pandemic shock?
b) Does the influence of ICT on educational achievement apply equally to all students, or are certain groups benefiting more than others?

To answer these questions, we use data from the OECD's Programme for International Student Assessment (PISA). PISA is a large-scale international survey designed to evaluate the performance of 15-year-olds in the subjects: reading, mathematics, and science. By using data from PISA-2009 and 2018, our study employs a correlated random effects model to estimate the effect of using digital devices during the classroom lessons and outside of the classroom for the subject's math, science and reading. Drawing inspiration from Falck et al. (2018), we employ similar methodology, using the within-student between-subject variation to control for unobserved student characteristics. Their research analyses the effects of students' computer use in the classroom, with a particular emphasis on the use of computers for three computer-related tasks in the subject's math and science. Although, Falck et al. (2018) used TIMSS data which only focuses on mathematics and science, we chose not to use it due to our objective of exploring additional subjects. Our contribution is that we are focusing on both the use of digital devices during and outside of the classroom, for math and science as well as reading. Additionally, we investigate how the impact varies depending on the different time usage of digital devices and examine the evolving patterns between 2009 and 2018.

For the primary analysis, we will use the PISA-2018 dataset, although for the trend analysis, we will use data from 2009. Unfortunately, earlier datasets than 2009 aren't feasible due to limitations in digital device variables; our methodology requires subject-specific variables of digital device usage and not variables measuring the general usage.

Since we want to examine the impact before the COVID-19 shock, we decided not to use the newly released PISA dataset from 2022. The variables related to ICT in the PISA-2022 dataset were also not compatible with our selection of digital device variables. The only ICT variable linked to specific subjects in PISA-2022 was as follows: *"How often do you use digital resources in the following classroom lessons?"* with response options ranging from "Never or almost never" to "In every or almost every lesson". Given that our digital device usage variables focus on the weekly amount of time spent during classroom lessons or outside the classroom for specific subjects, the results would not be directly comparable.

Our study uses two different types of ICT variables to estimate the effect, first an index that measures the intensity of digital device usage and secondly variables based on the different time of usage. Our findings from the first approach, reveals a positive correlation between digital device usage and educational achievement. Specifically, using digital devices in the classroom correlated with increased test scores in math, while using it outside of the classroom had a positive impact on science and reading test scores. However, our findings from the second approach reveals that not using digital devices has a negative impact on test scores, while an increased usage doesn't significantly impact test scores. Interestingly, it seems that not using digital devices creates a penalty for students. This implies that the impact of using digital devices depends more on whether they are used or not, rather the amount of time using digital devices. Moreover, our findings indicate that digital devices can offer additional support to students from disadvantaged backgrounds or those with lower academic performance.

The remainder of the paper is organised as follows: Section 2 summarizes the main results in the literature on ICT and educational achievement. Section 3 presents the data and selection of variables. Section 4 describes the methodological approach and strategy. Section 5 presents the main findings. Section 6 discuss the main findings and limitations of the study. Lastly, section 7 will conclude.

## 2. Literature Review

Despite the common belief in technology's exceptional benefits for learning, the results of previous findings have been inconclusive, as noted in Bulman and Fairlie's (2016) comprehensive review of previous literature on the impacts of technology on educational outcomes. While some studies suggest a positive correlation between technology and learning outcomes, others reveal more modest gains or even negative relationship.

The extensive literature examines two key contexts for technology use in education, within the school classrooms and at home. Understanding the fundamental difference between these situations is important. In the school setting, decisions regarding ICT usage are made by districts and schools, influencing the extent of investment in technology and determining how it should be integrated into the learning process. While in the home environment, the responsibility for investing in and using technology rests with parents and students. This contrast underscores the importance of considering both institutional and familial factors in understanding the effects of technology on learning outcomes.

### 2.1 Studies on ICT Investments and CAI Programs

Research in this area has primarily focused on two approaches: evaluating the effects of ICT investments and assessing the impact of CAI (computer-aided instructions) programs. ICT refers to the use of computers, software, and the internet while CAL is focused on how to use technology to assist the teaching and learning process. Previous studies on the effect of investments in computer hardware and software has typically conduct experimental studies that exploit policy variations regarding funding and randomized control trials (RTCs) (Bulman and Fairlie, 2016).

Leuven et al. (2007) examined the effects of a computer subsidy in the Netherlands, targeting schools with a large share of disadvantaged students. These schools were provided extra funding to purchase computers or software. The researchers employed a regression discontinuity design (RDD), defining the threshold as schools with at least 70% of students from ethnic minority backgrounds or with parents of low education levels. To evaluate the subsidy's impact on test-scores, the authors analyses data from national tests scores together with administrative data from 1998-1999, identifying which schools received funding. Surprisingly, their results revealed a negative and statistically insignificant effect on test scores. In contrast, Machin et al. (2007) evaluated a policy change regarding the governments allocation of ICT funds in England. Together with data from an ICT survey for both primary schools and secondary school in the period 1999-2003, they were able to apply an instrumental variable model to estimate the treatment effect. Unlike the findings of Leuven et al. (2007), the authors found a significant positive effect on test scores in science and english, while not for math. The authors suggest that the positive observed outcomes could be partially explained by the favorable starting position of schools that received ICT funding and being able to use the ICT inputs in a more efficient way.

Some studies have explored the efficacy of computer-aided instruction (CAI) programs. Barrow et al., (2009) conducted a randomized control trial (RCTs) to evaluate the effect of a CAI initiative in the United States. Using computer programs for pre-algebra and algebra, the study assesses whether computer-led instruction could outperform traditional teaching methods. To estimate the treatment effects, the authors conducted an ordinary least square regressions as well as instrumental variables regression to control that the students who was assigned to the class participated. By analyzing data from 2003-2004 and 2004-2005, the authors found that students who received computer-aided instruction achieved higher test scores compared to the students who received traditional teaching. This suggests that computer-aided instruction may be particularly effective for students in larger classes or those requiring additional support, benefiting from personalized instruction.

Similarly, Banerjee et al. (2007) used an RTC design to investigate the effects of computer-assisted learning program in math, this time in urban India and as a supplement rather than a substitute of traditional teaching. Students in the treatment group received two hours of computer time per week, with one hour during the classroom time and one hour outside of the classroom. The level of the educational games was adapted depending on the student's current level in math. The authors found that students in the treatment group, playing educational games, increased their math test scores. However, these positive effects faded over time.

In contrast, Linden (2008) explored the effect from the same computer assisted learning program. The author tries to separate the two potential effects from using the program, the effect from using it during the classroom as a substitute for traditional teaching and as a complement outside of the classroom. Using data from two randomized experiments in India, the author performed both an ordinary least square regressions (clustering the standard errors by schools) and a nested random effects model estimated by generalized least squares, to estimate the treatment effect. Surprisingly, the study revealed a negative effect when the program was used as a substitute for traditional teaching but a positive effect when employed as a complement outside of the classroom.

### 2.2 Large-Scale Survey Data Studies

Furthermore, a significant body of research has used large-scale survey data such as Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). These datasets offer standardized assessments and large-scale sample sizes, enabling comprehensive analyses and international comparisons.

In the study by Fernández-Gutiérrez et al. (2020), the authors explored the impact of a policy aimed at integrating ICT into teaching methods and its effect on students' test scores in math, science, and reading. The authors used the PISA dataset (2009, 2012, 2015) for the Spanish regions, the study focused specifically on autonomous communities that had implemented further efforts to increase ICT usage in schools. To assess the impact of ICT in schools, the authors used an index measuring the frequency of students' digital device usage across various activities. Employing a Hierarchical Linear Model (HLM), the study revealed a positive impact of increased ICT usage on science test scores in these autonomous communities. However, the effects on math and reading scores were not consistent, suggesting subject-specific variations.

Efficiency in implementing ICT by teachers and schools emerges as a crucial consideration, as highlighted by De Witte & Rogge (2014). Their study explored the causal relationship between ICT impact on student performance and the overall efficiency of educational processes. Using data from TIMSS 2011 in the Netherlands, they employed a matching approach, specifically Mahalanobis matching, to create artificial control and experimental groups with similar characteristics across students, teachers, and schools. Their analysis focused on two key ICT variables: the shortage of computers for instruction (reported by teachers) and the intensity of computer usage at school (reported by students). Their findings suggested that the observed effects among students in schools with or without ICT shortages may diminish when considering various background characteristics such as student, teacher, school, and district characteristics. This highlights the importance of accounting for these factors when evaluating the effectiveness of investments in educational technology. Additionally, the authors underscored the crucial role of teachers and their perspectives on integrating ICT into the learning process.

Moreover, studies such as Fuchs and Woessmann (2004) and Spiezia (2010) delve into the complexities of ICT usage both at home and in school. Fuchs and Woessmann (2004) conducted a study that examined the relationship between students' educational achievement in math and reading and the availability and usage of computers, both at home and at school. Using the PISA-2000 datasets with students from 31 countries, they initially found a positive relationship through bivariate analysis. However, after controlling for family background and school characteristics, they found the relationship negative between the availability of computer at home and insignificant for school computers. Interestingly, there is a positive relationship between the usage of computers at home and test scores, this usage was associated with accessing emails, webpages, and educational software. Moreover, the relationship between test scores and computer usage at school exhibited a U-shaped pattern, suggesting that relative usage increased test scores while excessive usage decreased them. These findings suggest that while the availability of computers may have some benefits, it could also potentially distract students from effective learning.

Spiezia (2010) further emphasizes the differential impact of computer usage at home versus school on science test scores, raising questions about the effectiveness of ICT integration in the classroom. Using data from PISA-2006 covering 33 countries, the study assessed the frequency of computer use and its impact on test scores in science, depending on whether it was used at home or school. By employing an ordered probit model and controlling for student and school characteristics, the author observed a positive effect of computers usage on science test scores. Notably, the study revealed that this effect was more pronounced when computers were used at home compared to in school. This finding underscores the necessity for policies aimed at optimizing computers as effective learning tools within the school environment, while also raising questions about the effectiveness of ICT in the classroom.

Examining students' attitudes towards ICT adds another layer of complexity to understanding its impact on educational achievement. In the study by Petko et al. (2017), explored the relationship between test scores and the use of ICT both in school and at home, while also considering students' attitudes towards ICT. Using data from PISA-2012 across 39 countries the study focused on test scores in math, reading, and science as dependent variables. Additionally, ICT variables included indexes, reflecting the computer usage at home for entertainment and educational purposes, as well as at school. The authors also included a variable assessing students' positive attitudes towards using ICT as a learning tool. By employing a weighted linear regression model, the study found that the usage of ICT in school was negatively correlated with test scores in all three subjects, whereas the usage of ICT at home for educational purposes had a positive effect. Furthermore, the results indicated a positive relationship between ICT usage and students' attitudes towards ICT in education, suggesting that students with a more positive attitude towards ICT achieved higher test scores. One of their key conclusions drawn from the study was that the quality, rather than the quantity, of ICT usage contributes significantly to positive outcomes.

### 2.3 Effectiveness of ICT in School and Home Environments

The debate surrounding the integration of ICT, whether within the home or school environments, is multifaceted, with numerous studies reporting null outcomes (Bulman & Fairlie, 2016). Falck et al. (2018) delve into this issue, acknowledging both positive and negative views. Their study introduces a fresh standpoint on ICT usage in schools, where they show that the null effect effects could arise from two different dynamics: using computers for tasks that work better than conventional teaching techniques and improving student outcomes, or using computers in a way that replaces more successful conventional practices and decreasing student outcomes. The authors use a correlated random effects model and exploit the within-student between-subject variation to estimate the different uses of computer tasks in the TIMSS-2011 dataset. Specifically focusing on math and science subjects, they identify that using computers for activities such as “looking up ideas and information” may improve the student’s test scores, while using it for “practicing skills” has a negative effect on the test scores. This shows that there is a potential null effect, for some tasks using computers might be more efficient compared to traditional teaching, while for other tasks it will be unproductive – opportunity cost of time.

Similarly, Comi et al. (2017) reports a similar null effect, while using a similar approach to Falck et al. (2018). Focused on data from Northern Italy, this study delved into the use of computers by teachers rather than solely focusing on student usage during classroom sessions. Using data from 2012, which contained information on both students and teachers, the authors conducted their analysis using a within-student between-subject estimator, specifically examining the disparity between students' performance in math and Italian-language subjects. Their key findings emphasize the pivotal role of teachers in determining the effectiveness of ICT in educational settings, dependent upon how teachers integrate it into their teaching practices. Positive effects were evident when teachers incorporated computers to teach critical internet skills or employed them for communication purposes with students, families, and colleagues. Conversely, negative effects were observed when students were required to undertake a more active role in the classroom, such as when they were required to use software during lessons.

Both the studies by Falck et al. (2018) and Comi et al. (2017) center on computer usage in school environments, overlooking the effect of usage within the home. In contrast, Agasisti et al. (2020) build upon insights from Falck et al. (2018), acknowledging that certain computer usages are productive while others are not, and extend this understanding to home environments. By employing a propensity score matching technique, they explore the relationship between students' test scores in three subjects (reading, math, and science) within the PISA 2012 dataset and the use of ICT at home for school-related tasks across 12 European countries. They used an index variable measuring the frequency of tasks performed on a home computer for school-related purposes, categorizing students in the first quartile of this distribution into the experimental group, with the remainder forming the control group. Their analysis unveiled a negative impact of using ICT at home for school-related tasks on students' academic performance. Furthermore, they noted no noticeable differences between low-performing and high-performing students in this regard.

### 2.4 Summary and contribution to previous literature

Previous literature on technology's impact on educational achievement has found conflicting findings, emphasizing the nuanced effects of ICT availability and usage, particularly across home and school environments as well as subject areas. While some studies demonstrate positive correlations, others reveal modest gains or even negative relationships. Previous studies underscore the significance of considering both institutional and family factors when exploring technology's influence on learning outcomes (Fuchs and Woessmann, 2004). Moreover, the literature highlights the necessity of carefully examining the potential trade-offs associated with technology investments and usage. Investments for educational purposes may impact other essential inputs that are affecting student achievements or substitute traditional education with computer-based methods, whose effectiveness is not always guaranteed (Bulman and Fairlie, 2016).

In our study, we advance existing research by delving into the variability of ICT's impact across subjects and settings, while addressing potential sample biases and controlling for student and family background factors. Through our investigation of both home and school environments, we aim to offer a comprehensive understanding of ICT's effects on educational achievement. A crucial aspect of our study is the exploration of how the intensity of ICT usage affects students, particularly comparing non-users with those who engage with it extensively. Furthermore, our research contributes to the literature by analyzing how different subgroups may be differentially affected by ICT usage.

## 3. Data

### 3.1 Source of Data

This study uses data from the OECD's Programme for International Student Assessment (PISA) from the 2018 and 2009 editions. PISA is a large-scale international survey that is conducted every three years, designed to evaluate the performance of 15-year-olds in the subjects: reading, mathematics, and science. The survey gathers information from individual students, school principals and parents through various questionnaires, providing insight into student's backgrounds and learning environments. For our analysis, we include variables from the ICT familiarity questionnaire, a part of the student questionnaire dataset that contains the key variables related to the main focus of our study. The main analysis of this study is from 2018, however, we will also incorporate data from 2009 which allows us to examine and comprehend potential changes in the impact of digital device usage on educational achievement over the ten years.

The PISA dataset includes both OECD and non-OECD countries, resulting in 78 participating countries in 2018. While previous studies like Petko et al. (2017) and Falck et al. (2018)[1] employed samples comprising both OECD and non-OECD nations, we opted for a more homogeneous group of countries focusing on European countries similar to Agasisti et al. (2020).

However, due to the optional nature of the ICT familiarity questionnaire, some participating countries provided incomplete responses, posing constraints on which countries could be included in our study. This issue has been encountered by previous studies like Agasisti et al. (2020), which had to restrict their sample from EU15 to only include specific countries such as Austria, Belgium, Denmark, Finland, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, and Sweden. Moreover, our selection of countries faced further constraints due to disparities in missing ICT variables between the datasets from 2009 and 2018. Consequently, our final selection for this study includes Belgium, Denmark, Finland, Greece, Ireland, Iceland, Italy, and Spain[2].

### 3.2 Test Scores

The dependent variables in this study are the test scores in math, science and reading. However, in PISA dataset, these test scores are presented as plausible values. For our analysis, we will use the

[1] Petko et al. (2017) used data from PISA 2012 meanwhile Falck et al. (2018) used TIMSS data from 2011.
[2] Throughout the analysis, we have adjusted for sampling probability, applying weights derived from the survey design to make sure the countries receive the same weight. See table A5 in appendix for summary statistics of the specific countries.

first plausible value for math, science, and reading, consistent with the approach adopted by Falck et al. (2018) in their study. In addition, Agasisti et al. (2020) reference to a comment from OECD regarding using plausible values, OECD (2009, 129): "*On average, analyzing one plausible value instead of the average of five plausible values provides unbiased population estimates, as well as unbiased sampling variances on these estimates*". Furthermore, considering that previous research has found that the impact of ICT depends on the subjects it is applied to (Fernández-Gutiérrez et al., 2020), it becomes interesting to investigate math and science as well as go a step further by incorporating reading, which is a dimension not explored in the paper by Falck et al. (2018). Lastly, the test scores have been normalized to mean 0 and standard deviation 1.

### 3.3 Determinants of Test Scores

To determine which variables to include we used the education production function, where a specific output (test scores) is produced depending on the combination of inputs (Hanushek, 2002). The selection of input variables for this study includes variables on individual characteristics, family background, and ICT variables. Tables A1 and A2 provides a list of the control variables including descriptive statistics. The selection of the variables controlling for individual characteristics and family background is taken mostly from the Hanushek and Woessmann (2011). The authors discuss international differences in educational achievement and include previous studies on which factors have an impact on educational achievement. As for the ICT variables, we draw inspiration from Falck et al (2018) and from Bulman & Fairlie (2016).

#### 3.3.1 ICT variables

The study focuses on digital device usage during classroom lessons and outside the classroom, either at home or in school for specific subjects. Previous research highlights the varying impact of ICT based on availability, type, and subject (Fernández-Gutiérrez et al., 2020). To explore this, we examine digital device usage across different subjects using two approaches: an index variable and time using variables. While the index variable offers comparability with Falck et al. (2018), its limited ability to capture usage patterns restricts analysis depth. By incorporating the time using variables, we overcome this limitation, providing deeper insights into usage patterns and their effects on test scores. This dual approach enabling us to extract more meaningful insights regarding the effects of ICT usage on educational achievement.

*Digital device usage variables*

*i. Intensity of using ICT (Index)*

For each subject, the variables are coded as follows: if the student doesn't use digital devices during classroom lessons or outside the classroom for the specific subject it takes the value "1", if it uses it around 1-31 minutes a week it takes the value "2", if it uses it 31-60 minutes a week "3" and if the student uses it more than 60 minutes a week it takes the value "4". In our regression analysis, we normalized the variables for digital device usage in each subject to have a mean of 0 and a standard deviation of 1.

*ii. Weekly Digital Device Usage*

Additionally, another approach to measure the impact of digital device usage on test scores is to explore how it depends on whether the student don't use digital devices at all during or outside the classroom, compared to using them for more than 60 minutes or more a week. Two new binary variables were created for the usage of digital devices during and outside the classroom for each subject[3].

*Descriptive evidence of ICT Usage among students*

The key findings from the descriptive statistics on ICT usage in our sample shows that a large share of students does not use digital devices, and usage differs between subjects and the learning environment.

The usage of digital devices among students in the 2018 sample appears relatively low, as illustrated in table 1, which presents descriptive statistics for digital device usage and the distribution of students across each category. The majority of students refrain from using digital devices entirely, although this percentage is lower for usage outside the classroom. Specifically, around 36.2% use digital devices during the classroom lessons for math, 44.9% for science, and 42.3% for reading. Outside the classroom, these figures increase to 47.2% for math, 53.7% for science, and 56.4% for reading. Comparing with the 2009 sample, even less students uses digital

[3] "No time" variable takes the value "1" if the student doesn't use digital devices during and outside the classroom in both subjects used in the SUR regressions, and "0" if it uses them. "More than 60 minutes a week" variable takes the value "1" if the student uses digital devices for more than 60 minutes a week both during and outside the classroom in both subjects.

devices during the classroom lessons. Table 2 show that around 13.9% use digital devices during the classroom lessons for math, 16.9% for science and 16.5% for reading.

TABLE 1

*Summary statistics of digital device usage, 2018 sample*

| | Intensity of using digital devices | | Separate categories of digital device usage | | | |
|---|---|---|---|---|---|---|
| | Mean (1) | Std. Dev. (2) | No time (3) | 1 – 30 min a week (4) | 31–60 min a week (5) | More than 60 min a week (6) |
| **Math** | | | | | | |
| Using digital devices during classroom lessons | 1.6701 | 1.0270 | 0.6381 | 0.1623 | 0.0909 | 0.1087 |
| Using digital devices outside of classroom lessons | 1.7584 | 0.9587 | 0.5283 | 0.2662 | 0.1243 | 0.0812 |
| **Science** | | | | | | |
| Using digital devices during classroom lessons | 1.8272 | 1.0733 | 0.5511 | 0.1970 | 0.1257 | 0.1263 |
| Using digital devices outside of classroom lessons | 1.8698 | 0.9810 | 0.4631 | 0.2956 | 0.1495 | 0.0917 |
| **Reading** | | | | | | |
| Using digital devices during classroom lessons | 1.7541 | 1.03846 | 0.5774 | 0.2063 | 0.1013 | 0.1151 |
| Using digital devices outside of classroom lessons | 1.8894 | 0.9641 | 0.4358 | 0.3294 | 0.1445 | 0.0904 |

*Notes:* PISA sample 2018. Columns (1)-(2): Mean and standard deviation of digital device use during and outside classroom lessons in the respective subject (1 = no time, 2 = 1-30 minutes a week, 3 = 31-60 minutes a week, 4 = More than 60 minutes a week. Columns (3)–(6): Share of students in the respective category of digital device use during and outside the classroom. Observations: 59,604.

The descriptive statics presented in table A3 and table A4 in the appendix, show that for both the 2009 and the 2018 sample, there is a big difference between the share of students that doesn't use digital devices compared to students who uses it for more than 60 minutes a week. Additionally, the tables show that there is an increase of digital device usage among student between 2009 and 2018. The share of student using digital devices during the classroom lessons for more than 60 minutes a week increased from 3.1% to 10.9% in math, for science it increased from 2.2% to 12.6% and for reading 2.7% to 9.0%.

TABLE 2

*Summary statistics of digital device usage, 2009 sample*

| | Intensity of using digital devices | | Separate categories of digital device usage | | | |
|---|---|---|---|---|---|---|
| | Mean (1) | Std. Dev. (2) | No time (3) | 1 – 30 min a week (4) | 31–60 min a week (5) | More than 60 min a week (6) |
| **Math** | | | | | | |
| Using digital devices during classroom lessons | 1.3318 | 0.7475 | 0.8610 | 0.0866 | 0.0767 | 0.0306 |
| **Science** | | | | | | |
| Using digital devices during classroom lessons | 1.2632 | 0.6513 | 0.8303 | 0.0979 | 0.0502 | 0.0216 |
| **Reading** | | | | | | |
| Using digital devices during classroom lessons | 1.2665 | 0.6724 | 0.8350 | 0.0906 | 0.0476 | 0.0269 |

*Notes:* PISA sample 2009. Columns (1)-(2): Mean and standard deviation of digital device use during classroom lessons in the respective subject (1 = no time, 2 = 1-30 minutes a week, 3 = 31-60 minutes a week, 4 = More than 60 minutes a week. Columns (3)–(6): Share of students in the respective category of digital device use during the classroom. Observations: 82,828.

*ICT Control variables*

We incorporated several ICT control variables, including two to assess the availability of ICT at home. The first variable checks if the student has an internet connection at home and actively uses it. The second variable examines whether the student possesses either a laptop or desktop computer at home, which they actively use. Additionally, two other variables are integrated to measure in general the extent of the student's digital device usage at home. One variable captures the frequency of internet browsing for schoolwork, while the other assesses the use of digital devices at home for tasks like browsing the school website for course materials. These variables consider whether the student engages in these activities almost every day or every day.

In the appendix table A1, displays descriptive statistics for our control variables for 2018 sample, and reveals that 89.4% of students have access to either a laptop or desktop computer at home, while 95.8% have internet access at home. However, only about 23.9% use digital devices at home for schoolwork almost every day/every day, and roughly 17.5% use them for tasks like browsing course materials almost every day/every day. As for the 2009 sample, the descriptive statistics for our control variables are presented in the appendix table A2. Around 94.0% of students have access to either a laptop or desktop computer at home, while 86.8% have internet access at home. Compared to the 2018 sample the everyday usage of digital devices at home is smaller, only 13.8% use digital devices at home for schoolwork almost every day/every day, and roughly 6.5% use them for tasks like browsing course materials almost every day/every day.

### 3.3.2 Individual characteristics

To control for the student's characteristics, we include variables such as age, gender, grade repetition, grade, attendance in pre-primary school, and attitude towards learning, see tables A1 and A2 in the appendix for descriptive statistics.

*Age*

While the questionnaire specifically targets 15-year-olds, the variable "age" considers the birth month of students, distinguishing between individuals born earlier or later in the year. In some cases, children born earlier in the year may commence school earlier, potentially influencing their performance positively (Leuven et al. 2010, Bedard and Dhuey, 2006).

*Gender*

The variable female is included to control for the gender gender's impact on educational achievement. The variable will be further used when investigating if there is a difference between the gender's digital device usage and the impact it has on test scores.

*Relative Grade Index*

The relative grade index that is computed by PISA is included to account for between-country variations. It indicates whether students are below or above the modal grade within a country (0 for modal grade).

*Grade Repetition*

The grade repetition variable indicates if a student has repeated a grade in at least one of the ISCED levels 1, 2 or 3. This variable is included to consider the impact of students who may have encountered academic challenges, as well as other factors such as adapting to a learning disability or transitioning from another school.

*Attendance of pre-primary school*

The inclusion of the variable "pre-primary school" serves to control for the influence of pre-primary attendance on academic achievement, in this case, if the student has attended pre-primary school for more than one year. Previous studies have consistently demonstrated a positive correlation between attendance at pre-primary school and students' test scores (Hanushek and Woessmann, 2011; Schuetz, 2009).

*Attitude towards learning*

Lastly, we include a variable to control for the student's attitude towards learning in school, which can be used as a proxy for motivation. In the 2018 sample, the variable assesses whether the student agrees that the primary goal is to learn as much as possible in school. However, in the 2009 sample, the corresponding variable is a bit different and measures whether the student strongly disagrees that school is a waste of time.

### 3.3.3 Family Background

To account for the impact of family backgrounds, variables such as immigrant status, mothers' and dads' education level, the number of books at home, and whether the pupil has their own room are included. See tables A1 and A2 in the appendix for descriptive statistics.

*Immigrant Status*

The immigrant status variable categorizes students as either native or having an immigrant background (first or second generation). Previous research highlights achievement differences between immigrants and natives, potentially influenced by variations in language skills, socioeconomic background, and school segregation (Hanushek and Woessmann, 2011; Schnepf, 2007).

*Parental Education*

Inclusion of variables for parental education, reflecting the highest education level attained by the mother and father, is intended to assess the influence of parental education on students' academic performance. This encompasses not only the impact on parental involvement but also potential sorting mechanisms and informed educational choices, given that parents with higher education levels tend to invest more in their children's education (Freeman et al., 2014).

*The number of books at home*

Another variable that can be used as a proxy for the socioeconomic background is the number of books in the home. According to Woessmann, the number of books at home is considered a more superior indicator than parents' education due to its comparability between countries and being a significant indicator of educational achievement in most countries (Hanushek and Woessmann, 2011, Woessmann, 2003b, 2008). If the student has more than 200 books in the home it indicates a higher socio-economic status (SES) of the family. Mothers' education and number of books at home will be further used when investigating the differences in digital device usage and its impact on test score between students from different socio-economic backgrounds.

### 3.3.4 School control variables

The chosen school-level variables are consistent with the education production function outlined by Hanushek and Woessmann (2011) and were also used in the study conducted by Falck et al. (2018). These variables include school size, community location, the share of non-native speaking students, as well as indicators of potential instructional hindrances, such as the lack of physical infrastructure or a shortage of teaching staff. While there are additional variables related to school inputs and institutional features, such as class size, expenditures, accountability measures, and school autonomy (Hanushek and Woessmann, 2011), our focus on understanding the impact of ICT on student achievements leads us to consider the selected variables sufficient. Furthermore, in the study by Falck et al. (2018), the authors perform regressions where they have included teacher and teaching-method controls variables as well. In our sample, Spain is the only country among our selected countries that provided responses to the teacher questionnaire. Therefore, we are not able to perform a teacher analysis for our full sample.[4]

4 . It's worth noting that we did a regression for Spain where we included control variables for teachers and teaching methods, similar to the variables included in Falck et al. (2018). We observed that the coefficients remained relatively similar, however, the introduction of these additional variables led to an increase in the $R^2$ value. This increase in $R^2$ suggests that accounting for teacher characteristics and methods enhanced the overall explanatory power of our model.

## 4. Methodology

In the extensive body of economic literature on educational achievement, researchers have explored various topics, including the impact of family background and school inputs on test scores. Hanushek and Woessmann (2011), conducted a comprehensive review of previous research on international differences in educational achievements, including studies with a focus on both within-country and cross-country. These studies often rely on datasets such as PIRLS, TIMSS, and PISA. Example of commonly used analytical methods includes, Panel SUR regression, weighted clustering-robust linear regression, OLS ordinary least squares, IV instrumental variable, hierarchical linear modeling, data envelopment analysis, and decomposition models like Oaxaca-Blinder/Juhn-Murphy Pierce.

Building on the study by Falck et al. (2018), we use a correlated random effects model (CRE) estimated through seemingly unrelated regressions (SUR). The authors argue that this model is preferable to ordinary least squares (OLS), since the OLS coefficients are more prone to potential biases. The selection biases may arise from the non-random exposure of ICT among students within specific schools or classrooms. Considering that the impact of ICT usage may be influenced by various school and neighborhood characteristics, socio-economic background, or ability, the variations in ICT usage are unlikely to be exogenous. By employing a random effects model, we can account for unobserved heterogeneity among schools and students, thereby providing a more robust analysis of the data.

### Correlated random effects model

This study is inspired by prior studies that have exploit the within-student between-subject variation to gain detailed insights into ICT usage in education. This strategy employs such variation to account for subject-invariant unobserved attributes of both schools and students. By leveraging the differences in digital device usage between subjects within each student in our sample, the aim is to understand the impact of digital device usage on test scores and see if there are any significant variations across subjects.

To estimate the effect of using digital devices in education, the following education production function will be used:

$$A_{ij} = ICT_{ij}^{S} \beta_j^{S} + ICT_{ij}^{H} \beta_j^{H} + X_i \alpha + \mu_i + \varepsilon_{ij} \quad (1)$$

Where $A_{ij}$ is test scores of student $i$ in subject $j$ - either mathematics (math) or science (sci)[5], ICT is time spent using digital devices during the classroom lessons (S) or outside the classroom lessons (H). $X_i$ is a vector of control variables such as student and family background, school, and other ICT variables. The error term contains $\mu_i$, which is the error term specific to the student and $\varepsilon_{si}$ which is the error term specific for the student within subject j. Equation (2) is the education production for the subject math and equation (3) is for the subject science.

$$A_{i,math} = ICT_{i,math}^{S}\, \beta_{math}^{S} + ICT_{i,math}^{H}\, \beta_{math}^{H} + X_i \alpha + \mu_i + \varepsilon_{i,math} \tag{2}$$

$$A_{i,sci} = ICT_{i,sci}^{S}\, \beta_{sci}^{S} + ICT_{i,sci}^{H}\, \beta_{sci}^{H} + X_i \alpha + \mu_i + \varepsilon_{i,sci} \tag{3}$$

Since the aim is to estimate the subject-specific effects of using digital devices during classroom lessons (S) and outside the classroom (H) on educational achievement A, using the traditional fixed effects model might not be the most optimal approach. The fixed effects model relies on the assumption that the effect of using digital devices is consistent across subjects. Previous research has used the correlated random effects model instead, a similar method as the fixed effects model but relaxes the assumptions to be subject-specific allowing for a more nuanced exploration of subject-specific influences (Falck et al., 2018). In the paper by Wooldridge (2010), the author discusses Chamberlain's (1982) approach for estimating unobserved effects models. Chamberlain's method involves substituting the unobserved effect $\mu_i$ with its linear projection onto the explanatory variables across two time periods, including the projection error $\omega_i$ (Chamberlain, 1982; Wooldridge, 2010). In this case the unobserved effect $\mu_i$ represents the student-specific error component and instead of using explanatory variables across two time periods, the two subjects are used instead as demonstrated in the work by Falck et al. (2018). By linearly projecting the unobserved student-specific error component onto the explanatory variables, we can explore the relationship between $\mu_i$ and the subject-varying explanatory variables ($ICT_{i,s}^{S}$, $ICT_{i,s}^{H}$). From equation (2) and (3), we use student-specific error component $\mu_i$ and the explanatory variables to get the unobserved effect:

[5] The model uses two subjects, in this case math and science will be used as an example but it works in the same way when estimating either "Math and Read" or "Read and Science".

$$\mu_i = ICT^S_{i,math} * \eta^S_{math} + ICT^H_{i,math} * \eta^H_{math} + ICT^S_{i,sci} * \eta^S_{sci} + ICT^H_{i,sci} * \eta^H_{sci} + X_i\phi + \omega_i \quad (4)$$

Where the projection term $\omega_i$ is uncorrelated with $ICT^S_{i,s}$ , $ICT^H_{i,s}$ and $X_i$. Plugging equation (4) into equation (2) and (3), gives us the two following equations:

$$A_{i,math} = ICT^S_{i,math}\,(\beta^S_{math} + \eta^S_{math}) + ICT^H_{i,math}\left(\beta^H_{math} + \eta^H_{math}\right) + ICT^S_{i,sci} * \eta^S_{sci} + ICT^H_{i,sci} * \eta^H_{sci} + X_i(\alpha + \phi) + \mu_i + \varepsilon'_{i,math} \quad (5)$$

$$A_{i,sci} = ICT^S_{i,sci}\,(\beta^S_{sci} + \eta^S_{sci}) + ICT^H_{i,sci}\,(\beta^H_{sci} + \eta^H_{sci}) + ICT^S_{i,math} * \eta^S_{math} + ICT^H_{i,math} * \eta^H_{math} + X_i(\alpha + \phi) + \mu_i + \varepsilon'_{i,sci} \quad (6)$$

where, $\varepsilon'_{si} = \varepsilon_{si} + \omega_i$. In our modified subject-specific equations, we include both variables representing digital device usage for each respective subject. Specifically, when regressing math test scores on the usage of digital devices in math, we also incorporate the usage of digital devices in science. This ensures that the impact of digital devices on math is estimated while holding the influence of science constant, and vice versa.

The selection terms $\eta$ quantify the extent to which the relationship between digital device usage and test scores in math is distorted by the concurrent use of digital devices for activities related to the other subject, and vice versa. In simpler terms, they measure how much the coefficients for digital device usage deviate from their true effects due to the influence of digital device usage in the other subject.

This approach makes it possible to estimate the subject-specific effect that digital devices have on science and math. This estimation is carried out through equations (5) and (6), which represent our random effects model and are jointly estimated using the seemingly unrelated regressions (SUR) method. In SUR, it is assumed that the error terms from the two equations are correlated. If this correlation exists, it should lead to a more precise estimation of the impact that the usage of digital devices during and outside of the classroom has on student achievement. In the study by Falck et al. (2018), the authors provide an example, where the error terms could be correlated due to a student having a challenging testing day. Factors such as inadequate sleep or stress could likely affect the performance in the test, impacting both subjects. After estimating the correlated random effect model by SUR, the coefficients for the implied betas are given by the below equations:

$$\hat{\beta}_{math,} = \hat{\theta}^{5}_{math} - \hat{\theta}^{6}_{math} \quad (7)$$

$$\hat{\beta}_{sci} = \hat{\theta}^{6}_{sci} - \hat{\theta}^{5}_{sci} \quad (8)$$

where 5 and 6 refer to the respective equations for math and science, respectively. The calculation for the implied betas is calculated separately for $ICT^{S}_{i,s}$ and, $ICT^{H}_{i,s}$. Essentially, we can estimate the effect that usage of digital devices has on test scores in math by taking the difference between the coefficient associated with usage of digital devices in math in equation (5) to its counterpart in the equation (6). Similarly, the opposite is applicable when examining the impact of the usage of digital devices in science.

As its mentioned in the paper by Falck et al. (2018), our correlated random effects model that we're using in this study includes the traditional fixed effects model. To illustrate this, let's consider when the impact of digital devices on both subjects is the same, represented by $\beta_{math} = \beta_{sci}$ , and the selection terms for both subjects are equal, denoted as $\eta_{math} = \eta_{sci}$. These conditions, which assume equal effects and selection terms across subjects, are the identifying assumptions typically associated with the fixed effects model. When these assumptions are incorporated into our equations (5) and (6), and we calculate the discrepancy between the two subject-specific equations, we derive the fixed effects model expressed in a first-difference form.[6] These identifying assumptions can be tested with the help of equation (7) and (8), the test for $\beta_{math} = \beta_{sci}$ is given by $\hat{\theta}^{5}_{math} - \hat{\theta}^{6}_{math} = \hat{\theta}^{6}_{sci} - \hat{\theta}^{5}_{sci}$ and the test for $\eta_{math} = \eta_{sci}$ is given by $\hat{\theta}^{6}_{math} = \hat{\theta}^{5}_{sci}$.

[6] $\Delta A_i = \Delta ICT^{S}_{i}\beta^{S} + \Delta ICT^{H}_{i}\beta^{H} + \Delta v_i$.

## 5. Results – Correlated Random Effects Model

In this part, we present the findings of our study, focusing on the impact of digital device usage on test scores as measured by both index variables and time using variables. Section 5.1 delves into the results obtained when using the digital device usage index, primarily for comparison with the findings of Falck et al. (2018). This comparison allows us to assess whether our results deviate from theirs or if a similar pattern emerges. In section 5.2, we explore the impact of digital device usage when it is used "No Time" and "More than 60 minutes", shedding light on the effects of different usage levels on test scores. Additionally, in section 5.3 we analyze how the impact of using digital devices differs across different groups of students by gender, family background, and performance level. Lastly, in section 5.4 we will examine the potential trend of using digital devices in the last decade and its impact on educational achievement.

### 5.1 Digital Device Usage Index

*Impact on Test Scores*

Table 3 shows that using digital devices only has a significant effect when used during classroom lessons and is only significant for math. From column (1), the implied $\beta^S$ indicates that if there is a one-standard-deviation increase in the intensity of using digital devices during classroom lessons, then it increases math test scores by 2.5% of a standard deviation.

The effect remains almost the same when school control variables are included, as shown in column (2), where a one-standard-deviation increase in the intensity of using digital devices during classroom lessons increases math test scores by 2.5% of a standard deviation. Furthermore, the statistically significant difference between the coefficient for the implied betas for math and science suggests a subject-specific impact of using digital devices in the classroom, indicating that the effect of digital device usage may vary between subjects .

In the study by Falck et al. (2018), the authors included variables for specific computer use task as well as a "combined computer use", which is constructed by combining the three specific computers uses variables into an index[7]. In their results for the 8th grade sample, the authors found

[7] The combined computer use variable was constructed as an index of the three specific computer uses variables ("Look up ideas and information", "Practice skills and procedures", "Process and analyze data").

TABLE 3

*Within-student between- subject estimation, 2018 sample*

| | (1) | | (2) | |
|---|---|---|---|---|
| | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | |
| Implied $\beta^S$ | 0.0250*** | 0.0076 | 0.0247*** | 0.0065 |
| | [12.29] | [1.38] | [12.14] | [1.04] |
| $\beta_{math} - \beta_{sci}$ | 0.0175*** | | 0.0182*** | |
| $\eta_{math} - \eta_{sci}$ | -0.0693*** | | -0.0715*** | |
| Using digital devices outside of classroom lessons | | | | |
| Implied $\beta^H$ | 0.0097 | 0.0086 | 0.0068 | 0.0083 |
| | [1.97] | [1.87] | [1.00] | [1.75] |
| $\beta_{math} - \beta_{sci}$ | 0.0010 | | -0.0014 | |
| $\eta_{math} - \eta_{sci}$ | -0.1334*** | | -0.1385*** | |
| Student controls | Yes | | Yes | |
| School controls | No | | Yes | |
| Observations | 59.602 | | 59.602 | |
| Clusters | 2.691 | | 2.691 | |
| $R^2$ | 0.2320 | 0.2092 | 0.2471 | 0.2170 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and science. Test scores and the two variables in table has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

only significant results for the science subjects, which is the opposite from our findings. Using classroom computer in science to look up ideas and information had a positive impact on the test scores, one-standard-deviation increase in the intensity of computer usage for that task increases science test scores by 6.0% of a standard deviation. Meanwhile using it to practice skills and procedures has a negative effect on the test scores in science, one-standard-deviation increase in the intensity of computer usage for this task decreases science test scores by 4.9% of a standard deviation[8]. Consistent with our findings, the estimated $\beta$ coefficients in their studies suggest that the impact of computer usage varies across specific subjects. Moreover, their analysis found

[8]The effect size becomes smaller when controlling for teacher and teaching-methods, from 6.0% to 3.3-4.1% and from -4.9% to -2.0-3.1%.

disparities in the estimated selection terms $\eta$ across the two subjects, thereby undermining the assumption of subject-invariant effects embedded within the fixed effects model[9]..

*Heterogeneity across countries*

Instead of just focusing on the average impact of digital devices on academic achievement, we delved deeper into how this impact varies across different countries. The effects we found are somewhat subtle and show distinct differences among countries, as detailed in tables A8 and A9 in the appendix. For instance, Finland shows a positive impact when using digital devices in math classrooms, while Belgium shows a negative effect, both during math classes and outside. Denmark and Iceland only show significant results when digital devices are used outside the classroom for math and science, respectively. On the other hand, Greece, Ireland, and Italy don't exhibit statistically significant results at the 5% significance level. Spain, interestingly, only demonstrates significant results in the science domain, similar results to the study by Fernández-Gutiérrez et al. (2020).

In table A10 in the appendix, we divided our sample into two groups: the "Nordics" (Denmark, Finland, and Iceland) and the "South" (Greece, Italy, and Spain). In the Nordics, the impact of digital device use is more pronounced than in the South when it comes to math test scores. Specifically, one-standard-deviation increase in the intensity of using digital devices during math classroom lessons increases test scores in the “Nordics” by 5.0% of a standard deviation and in the “South” by 3.1% of a standard deviation. In addition, in the Nordics, one-standard-deviation increase in the intensity of using digital devices during science classroom lessons decreases test scores by 4.1% of a standard deviation. The usage of digital devices outside the classroom has only a significant impact on math test scores in the Nordics. One-standard-deviation increase in the intensity of using digital devices outside the classroom lessons for science increases test scores by 4.9% of a standard deviation.

Overall, our findings suggest that the impact of using digital devices varies significantly among countries and exhibits a pronounced country-specific aspect, similar to the findings reported

[9] From the test of the estimated selections terms, a significant difference between the subjects is observed. This indicates that the influence of certain unobserved factors on the relationship between digital device usage and test scores varies depending on the subject. Following the findings of Falck et al. (2018), our study opts not to enforce constraints like $\eta_{math} = \eta_{sci}$ for individual variables. Their research concluded that imposing such restrictions offers minimal enhancements in estimation efficiency, therefore the selections term will only be showed in table 3 and table 6.

in the study by Falck et al. (2018). In their investigation, the authors explored potential heterogeneous effects across countries by dividing the sample into subgroups based on OECD and non-OECD members and other country characteristics[10]. Despite their efforts, the authors were unable to identify a distinct pattern of country heterogeneity in their dataset. Notably, significant positive and negative effects were primarily observed in developed countries, whereas developing countries did not exhibit any significant effects.

*Extending the study to the subject reading and writing*

Drawing inspiration from previous studies that have highlighted subject-specific effects of ICT, we found it intriguing to further investigate by incorporating the subject "Reading" into our analysis. In table A11 in the appendix, we explored pairs of subjects: "Math & Read" and "Read & Science" in addition to the conventional "Math & Science" pairing. A notable observation from the comparison of columns (1) and (2) is that reading has a significant impact only when digital devices are used outside the classroom lessons. In column (1), a one-standard-deviation increase in the intensity of using digital devices outside the classroom lessons for reading enhances test scores by 2.0% of a standard deviation. Conversely, for the subject math, a similar increase in the intensity of using digital devices during math classroom lessons improves test scores by 1.4% of a standard deviation. A significant difference appears between the subjects, both during and outside the classroom lessons. Noteworthy is that, when compared with previous results for math and science, the impact of using digital devices during classroom lessons in math is now smaller.

## 5.2 Weekly Digital Device Usage Variables

*Impact on Test Scores*

Transitioning from our previous approach of using index variables to measure the usage of digital devices during and outside classroom lessons, we will now use the two different time using variables “No time” and “More than 60 minutes a week”.

In table 4, column (1) shows the impact of not using any digital devices during or outside the classroom on test scores, and column (2) shows the impact of using digital devices for more than 60 minutes a week. Columns (3) and (4) incorporate school control variables, however, the

[10] Country characteristics such as availability of broadband subscriptions, internet use in a country, educational spending, the per-capita number of computers, age structure and average use of computers in schools.

TABLE 4

*Within-student between-subject estimation depending on different digital device usage, 2018 sample*

| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
|---|---|---|---|---|---|---|---|---|
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0468*** [13.74] | -0.0043 [0.14] | 0.0402* [3.82] | 0.0082 [0.21] | -0.0459*** [13.46] | -0.0028 [0.06] | 0.0393* [3.66] | 0.0059 [0.11] |
| $\beta_{math} - \beta_{science}$ | -0.0425*** | | 0.0320* | | -0.0431*** | | 0.0334* | |
| $\eta_{math} - \eta_{science}$ | 0.1602*** | | -0.1178*** | | 0.1655*** | | -0.1189*** | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.02122* [3.50] | -0.0172 [2.51] | -0.0000 [0.00] | 0.0047 [0.04] | -0.0158 [1.93] | -0.0166 [2.35] | -0.0044 [0.03] | 0.0046 [0.04] |
| $\beta_{math} - \beta_{science}$ | -0.0040 | | -0.0047 | | 0.0008 | | -0.0090 | |
| $\eta_{math} - \eta_{science}$ | 0.2526*** | | -0.896*** | | 0.2614*** | | -0.1940*** | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | No | | No | | Yes | | Yes | |
| Observations | 59.602 | | 59.602 | | 59.602 | | 59.602 | |
| Clusters | 2.691 | | 2.691 | | 2.691 | | 2.691 | |
| $R^2$ | 0.2301 | 0.2082 | 0.2301 | 0.2048 | 0.2450 | 0.2159 | 0.2445 | 0.2122 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and science. The test scores have been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

effect remains similar to previous columns. The statistical significance is only observed for the usage of digital devices during classroom lessons, with no significant results found for usage outside the classroom. This significance is only notable within the subject of mathematics, at a 5% significance level. Specially, not using digital devices during classroom lessons decreases math test scores by 4.6-4.7% of a standard deviation (depending on including school controls). On the contrary, using digital devices for more than 60 minutes a week during classroom lessons does not have any significant impact on the test scores. Furthermore, a statistically significant difference is observed in the impact of not using digital device usage during classroom sessions between the two subjects.

Interestingly, our findings indicate that a higher usage of digital devices does not necessary yield a positive impact on students' test scores. This implies that the impact of using digital devices is not solely determined by the level of usage, but rather about using or not using digital devices. Similar results were found by Falck et al. (2018), in addition to using an index the authors used the indicator variables, "At least once per month" and "At least once per week" as well[11]. Their findings showed that the latter variable does not show a significant effect on test scores, suggesting that greater usage of computers does not necessarily lead to higher test scores.

*Heterogeneity across countries*

A comparison across countries was also conducted using categorical variables "No time" and "More than 60 minutes a week" instead of index variables. Table 5 presents the results for the two country groups, "Nordics" and "South".

Column (1) and (3), show that in both country groups, not using digital device during the math classroom lessons led to a decrease in math test scores by 11.2% and 5.5% of a standard deviation, respectively. Interestingly, in the "Nordics," not using digital devices during the science classroom lessons resulted in improved science test scores by 6.7% of a standard deviation. This may suggest that digital device usage may not be as beneficial in science classes as it is in math classes. Another noteworthy difference between the country groups is that using digital devices for more than 60 minutes a week had a significant impact only in the "Nordics". In this case, math test results increased by 12.3% of a standard deviation, while science test scores decreased by 7.6% of a standard deviation.

[11]In contrast to our study, the authors did not include a variable for students who do not use computers at all.

TABLE 5

*Within-student between- subject estimation depending on different digital device usage for North and South European countries, 2018 sample*

| | Nordics | | | | South | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a Week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.1122*** | 0.0674*** | 0.1226*** | -0.0763*** | -0.0553*** | -0.0043 | 0.0314 | 0.0159 |
| | [28.78] | [11.88] | [28.61] | [8.74] | [12.24] | [0.10] | [1.18] | [0.49] |
| $\beta_{maths} - \beta_{science}$ | -0.1796*** | | 0.1989*** | | 4.3168** | | 0.0155 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.1120*** | 0.0090 | 0.0679* | -0.0005 | -0.0083 | -0.0248* | -0.0231 | 0.0075 |
| | [27.56] | [0.22] | [3.79] | [0.00] | [0.35] | [3.39] | [0.60] | [0.08] |
| $\beta_{maths} - \beta_{science}$ | -0.1210*** | | 0.0684* | | 4.4158*** | | -0.0305 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 11.882 | | 11.882 | | 36.914 | | 36.914 | |
| Clusters | 582 | | 582 | | 1.708 | | 1.708 | |
| $R^2$ | 0.1632 | 0.1872 | 0.1682 | 0.1734 | 0.25772 | 0.2222 | 0.2546 | 0.2156 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The sample has been divided into two groups, the "Nordics" and the "South". "Nordics": consists of the countries Denmark, Finland, and Iceland. "South": consists of the countries Greece, Italy, and Spain. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

Tables A12 to A15 in the appendix present country-specific effects of using digital devices during and outside the classroom for the time using variables. Results vary depending on whether devices are used during or outside the classroom, as well as the subject. For instance, both Greece and Ireland (Table A14) did not show any significant results, while Spain (Table A15) and Iceland (Table A13) had a significant impact only in science, not math. Some countries, such as Denmark (Table A12), Iceland, and Italy (Table A15), showed no effect of using digital devices for more than 60 minutes.

*Extending the study to the subject reading and writing*

We examined how the two weekly digital device usage variables differ among the subject pairs: "Math & Read" and "Read & Science", the results are presented in table A16 in the appendix. Surprisingly, there is only a significant effect when examining the effect of not using it. For both subject pairs, using digital devices for more than 60 minutes a week does not have a statically significant impact on test scores, regardless of using it during or outside the classroom lessons don't have an impact on the test scores regardless of the subject pair.

In Columns (1) and (2), which focus on "Math & Read" results, it is observed that not using digital devices in the math classroom lessons results in a decrease in test scores by 2.8% of a standard deviation. For reading, not using digital devices outside of the classroom decreases test scores by 3.8% of a standard deviation.

Columns (3) and (4) present the outcomes for the subjects "Read & Science". The only statically significant results are for students who are not using digital devices outside of the classroom for reading, it decreases the test scores by 3.4% of standard deviation which is consistent to the results found for "Math & Read".

### 5.3 Heterogeneity across different groups of students

In this extension of our study, we aim to examine how the impact of using digital devices varies across different subgroups[12]. As previously mentioned, factors such as gender and socioeconomic background have been shown to influence students' test scores. It should be noted that for simplicity, we will use the weekly time usage variables "No time" and "More than 60 minutes a

[12] It's worth noting that while we observed variations in the impact of digital device usage on test scores among our subgroups, our analysis did not reveal any statistically significant differences between these subgroups.

week". While the findings using the index are similar, employing the weekly time usage variables offers a more intuitive way to interpret the results.

*Gender*

The first table of interest is table 6, where the sample has been divided by gender. Columns (1) and (2) shows a significant negative effect of not using digital devices during the math classroom lessons on the test scores for both genders. The negative effect is more pronounced for females, with males experiencing a decrease of 4.1% of a standard deviation in math test scores and females experiencing a decrease of 4.8% of a standard deviation in math test scores. Additionally, the observed impact of not using digital devices is statically difference between the subjects for both genders. In columns (3) and (4), it's evident that for both genders, using digital devices for more than 60 minutes a week does not yield a statistically significant impact on test scores at a 5% significance level.

*Family Background*

In table 7 and 8, the impact of digital device usage based on the student's socio-economic background is examined. In table 7, we use number of books in the household as a proxy for socio-economic background, dividing students into groups with low or high socioeconomic status[13]. In columns (1) and (2), not using digital devices during classroom lessons shows no significant effect on test scores for either subject at a 5% significance level, consistent across socio-economic groups.

In columns (3) and (4), using digital devices for more than 60 minutes a week during classroom lessons has a positive effect only for students with high socio-economic status. Specifically, it increases test scores in math by 7.4% of a standard deviation and in science by 6.0% of a standard deviation. Nevertheless, there is no statistically significant difference in the impact of the use of digital devices between the two subjects for any of the students. This indicates that digital device usage in school is primarily beneficial for students from higher socio-economic backgrounds. Students from lower socio-economic backgrounds may lack the same digital resources, potentially leading to less effective usage.

[13] If the student has more than 200 books at home the socio-economic status is high and if the student has less than 26 books at home it is considered low.

TABLE 6

*Within-student between-subject estimation by gender, 2018 sample*

| | No time | | | | More than 60 min a week | | | |
|---|---|---|---|---|---|---|---|---|
| | Male (1) | | Females (2) | | Male (3) | | Females (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0412** [4.85] | 0.0068 [0.13] | -0.0480 *** [7.57] | -0.0118 [0.68] | 0.0527* [3.09] | 0.0137 [0.27] | 0.0256 [0.92] | 0.0020 [0.01] |
| $\beta_{maths} - \beta_{science}$ | -0.0480*** | | -0.0362** | | 0.0454** | | 0.0236 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.0255* [2.78] | -0.0135 [0.64] | -0.0060 [0.14] | -0.0207 [2.49] | -0.0120 [0.10] | -0.0186 [0.31] | 0.0001 [0.00] | 0.0293 [0.95] |
| $\beta_{maths} - \beta_{science}$ | -0.0120 | | 0.0147 | | 0.0146 | | -0.0292 | |
| $\eta_{maths} - \eta_{science}$ | 0.2857*** | | 0.2373*** | | -0.1535*** | | -0.1673** | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 29.746 | | 29.857 | | 29.746 | | 29.857 | |
| Clusters | 2.610 | | 2.572 | | 2.610 | | 2.572 | |
| $R^2$ | 0.2510 | 0.2273 | 0.2374 | 0.2132 | 0.2468 | 0.2209 | 0.2407 | 0.2156 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The sample has been divided into "Males" and "Females". Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE 7

*Within-student between-subject estimation by socio-economic background depending on number of books at home, 2018 sample*

| | No time | | | | More than 60 minutes a week | | | |
|---|---|---|---|---|---|---|---|---|
| | Low (1) | | High (2) | | Low (3) | | High (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0423* | -0.0152 | -0.0330 | -0.0171 | 0.0060 | -0.0327 | 0.0735** | 0.0600** |
| | [3.22] | [0.33] | [2.08] | [0.70] | [0.02] | [0.59] | [5.12] | [4.14] |
| $\beta_{maths} - \beta_{science}$ | -0.0271 | | -0.0159 | | 0.0388 | | 0.0135 | |
| Using digital devices outside of classroom | | | | | | | | |
| Implied $\beta^H$ | -0.0126 | -0.0076 | -0.0015 | -0.0039 | 0.0391 | 0.0032 | -0.0312 | 0.0252 |
| | [0.23] | [0.06] | [0.01 | [0.04] | [0.58] | [0.00] | [0.43] | [0.44] |
| $\beta_{maths} - \beta_{science}$ | -0.0050 | | 0.0024 | | 0.0359 | | -0.0564 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 14.660 | | 13.940 | | 14.660 | | 13.940 | |
| Clusters | 2.536 | | 2.426 | | 2.536 | | 2.426 | |
| $R^2$ | 0.1857 | 0.1561 | 0.1689 | 0.1529 | 0.1866 | 0.1537 | 0.1696 | 0.1529 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The sample has been divided into subsample, where using books at home as a proxy for socio-economic background. "Low": If the student has less than 26 books at home. "High": The student has more than 200 books at home. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

In table 8, we use the mothers ‘education level as a proxy for socio-economic status[14]. Interestingly, columns (1) and (2), show that not using digital devices during classroom lessons significantly impacts test scores for both groups of students. The negative effect is more pronounced for students from lower socio-economic backgrounds, decreasing math scores by 7.1% of a standard deviation compared to 4.49% of a standard deviation for students from higher socio-economic backgrounds. However, a significant difference between the subjects' impacts is observed only for students from a high socio-economic background. In column (3) and (4), it shows that using digital devices for more than 60 minutes a week during the classroom lessons in math increases test scores by 6.2% of a standard deviation for students coming from a higher socio-economic background.

*Students' performance level*

In table 9, the sample is divided into two groups based on students' achievement levels: low and high achievers[15]. Interestingly, the table show that the impact of digital devices on test scores is only significant for low-performing students, particularly in the subject of math. Columns (1) and (2), show that not using digital devices during classroom lessons decreases math test scores by 11.2% of a standard deviation. Additionally, there is a significant difference in the impact of digital device usage on test scores between the two subjects.

In columns (3) and (4), it is observed that using digital devices during classroom lessons for more than 60 minutes a week increases the test scores of low-performing students in math by 10.9% of a standard deviation. Once again, the difference in the impact of digital device usage on test scores between the two subjects is significant.

### 5.4 ICT evolution from 2009 to 2018

In examining the evolving role of ICT in education within the current technological landscape, our aim was to determine whether its impact has kept pace with societal advancements or lagged behind. Interestingly, while our analysis using the index revealed an increase in the impact of using digital devices during classroom lessons on test scores between 2009 and 2018 which can be seen

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[14] If the student has a mother with less than a high-school education the socio-economic status is low and if the mother has a tertiary education (for example a university degree) it is high

[15] If a student's average grade is within the first quartile of the average grade in the sample, then they are considered "low" achievers and if they are within the fourth quartile they are "high"

TABLE 8

*Within-student between-subject estimation by socio-economic background depending on mother's education, 2018 sample*

| | No time | | | | More than 60 minutes a week | | | |
|---|---|---|---|---|---|---|---|---|
| | Low (1) | | High (2) | | Low (3) | | High (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0709** | -0.0126 | -0.0449*** | -0.0115 | 0.1458 | -0.0192 | 0.0615*** | 0.0282 |
| | [5.02] | [0.20] | [7.86] | [0.60] | [0.07] | [0.15] | [7.74] | [2.13] |
| $\beta_{maths} - \beta_{science}$ | -0.0583* | | -0.0333** | | 0.0338 | | 0.0347* | |
| Using digital devices outside of classroom | | | | | | | | |
| Implied $\beta^H$ | -0.0255 | -0.01174 | -0.0148 | -0.0225 | 0.0342 | 0.0020 | -0.0107 | -0.0013 |
| | [0.65] | [0.18] | [1.11] | [2.48] | [0.27] | [0.00] | [0.11] | [00 |
| $\beta_{maths} - \beta_{science}$ | -0.0137 | | 0.0077 | | 0.0323 | | 0.0079 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 9.625 | | 34.955 | | 9.625 | | 34.955 | |
| Clusters | 2.213 | | 2.620 | | 2.213 | | 2.620 | |
| $R^2$ | 0.2305 | 0.1915 | 0.2363 | 0.2064 | 0.2252 | 0.1813 | 0.2394 | 0.2070 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The sample has been divided into subsample, where using mother's education as a proxy for socio-economic background. "Low": If the student's mother has less than a high-school education. "High": The student's mother has a tertiary education or more. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equations 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE 9

*Within-student between subject estimation by student achievement, 2018 sample*

| | No time | | | | More than 60 minutes a week | | | |
|---|---|---|---|---|---|---|---|---|
| | Low (1) | | High (2) | | Low (3) | | High (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.1122****<br>[11.36] | -0.0033<br>[0.01] | -0.0069<br>[0.07] | -0.0098<br>[0.20] | 0.1092**<br>[5.87] | 0.0407<br>[1.02] | 0.0348<br>[0.96] | 0.0111<br>[0.23] |
| $\beta_{maths} - \beta_{science}$ | -0.1090*** | | 0.0028 | | 0.0685** | | 0.0237 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.0072<br>[0.06] | -0.0380<br>[1.61] | -0.0364*<br>[3.03] | -0.0173<br>[0.65] | 0.0087<br>[0.05] | 0.0160<br>[0.19] | 0.0203<br>[0.45] | 0.0014<br>[0.00] |
| $\beta_{maths} - \beta_{science}$ | 0.0307 | | -0.0191 | | -0.0073 | | 0.0189 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 10.457 | | 13.267 | | 10.457 | | 13.267 | |
| Clusters | 2.329 | | 2.215 | | 2.329 | | 2.215 | |
| $R^2$ | 0.0667 | 0.0518 | 0.0563 | 0.0352 | 0.0681 | 0.0428 | 0.0582 | 0.0347 |

*Notes*: PISA 2018 sample. Dependent variable: PISA student test scores in math and science. Comparing two groups of students, low and high achievers, if the students average test score (mean of test scores in math and science) is in the 1st quartile among the students then it belongs to group "Low" and if it's in the 4th quartile it is in the group "High." Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different categories "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

in table A6 in the appendix. Our examination of the time using variables yields a different insight. Specifically, table A7 in the appendix reveals that in 2018, not using digital devices during classroom lessons results in a negative effect on math test scores, a phenomenon not observed in 2009. Columns (1) and (2) present results for the 2009 sample, revealing that using digital devices for more than 60 minutes a week or not using digital devices is not statistically significant at a 5% significance level. Columns (3) and (4) present results for the 2018 sample, revealing that not using digital devices during classroom lessons in math decreases test scores by 5.0% of a standard deviation, while using devices for more than 60 minutes a week is not statistically significant at a 5% significance level. In addition, column (3) shows that there is a statistically significant difference in the impact of not using digital devices between subjects.

## 6. Discussion and limitations

The purpose of this study was to explore and analyze various aspects related to the impact of digital device usage on educational achievement across different subjects. In this study, we used a correlated random effects model to estimate the impact of using digital devices on educational achievement, this was done by using the within-student between-subject variation in two different digital device usage variables in the PISA dataset. Inspired by the approach introduced by Falck et al., (2018) we were able to get a better understanding of a) the correlation between using digital devices and educational achievement as well as explore how this correlation has evolved over time, and b) gaining a better understanding of who might benefit more from ICT.

### 6.1 The subject-specific effects underscore the need for a tailored approach

Our study highlights a subject-specific impact of digital device usage during classroom lessons, particularly notable for math compared to science. Interestingly, we observed a positive effect on test scores when digital devices were used during classroom lessons, contrary to previous studies (Petko et al., 2017; Spiezia, 2010), whereas usage outside the classroom showed no significance. Additionally, the results obtained from using the different time using variables revealed that not using digital devices during classroom lessons negatively impacted test scores, whereas using them for more than 60 minutes did not yield a statistically significant effect. This suggests that the quality, rather than the quantity, of digital device use may play a more influential role in educational achievement, in line with findings by Petko et al. (2017).

Furthermore, our analysis of implied betas revealed significant variations in the impact of digital device usage on test scores between subjects, indicating a subject-specific effect. This challenges the assumptions of the fixed effects model and aligns with the conclusions of Falck et al. (2018). Exploring the subject pairs "Math & Read" and "Read & Science" further underscored subject-specific impacts. Specifically, digital device usage predominantly influenced math test scores when used during classroom lessons, whereas for reading and science, the impact was significant when digital devices were used outside the classroom.

Our study sheds light on the penalties faced by students who either lack access to digital devices or for other reasons do not use digital devices, emphasizing the need for effective practices and policies for students. The modest overall effect of digital devices suggests digital devices should be viewed as a complement to traditional education rather than a substitute. The subject-specific effects underscore the need for a tailored approach, considering the different learning environments inside and outside the school. Lastly, teachers and schools play a crucial role in integrating digital tools into the learning process, as highlighted by previous research (Fernández-Gutiérrez et al., 2020; Comi et al., 2017; De Witte & Rogge, 2014)

### 6.2 Examining country-specific effects reveals no consistent pattern

The results across countries highlight significant variations in the impact of digital device usage on educational achievement, underscoring the influence of each country's unique educational landscape. Factors such as institutional differences, digital literacy levels, and policy variations contribute to these differences. Interestingly, our findings show that the Nordic countries which typically have a higher level of ICT integration in the countries, show significant results when using digital devices for more than 60 minutes a week in math. Conversely, countries in the south may not experience the same benefits due to lower ICT integration levels, leading to non-significant results. As mentioned earlier, countries with well-integrated ICT infrastructure are better positioned to facilitate digital learning effectively (Directorate-General for Education et al., 2023).

However, it's important to note that our study's limited sample of countries prevented us from identifying clear patterns based on ICT levels. Instead, the results mainly reflect country-specific effects, highlighting the need for further research to better understand the relationship between ICT integration and educational outcomes across different contexts.

### 6.3 Potential benefits of using digital devices for disadvantaged students

When comparing the impact of digital device usage based on socio-economic background using both the number of books in a household and mothers' education level as proxies, notable differences emerged[16]. Students from higher socio-economic backgrounds generally experienced more positive effects from digital device usage during classroom lessons, compared to students from lower socio-economic backgrounds, similar to the findings by Falck et al., (2018). This suggests that having greater access to digital resources might lead to higher levels of digital literacy, resulting in more substantial benefits from technology.

[16] Although no statistically significant differences found between the subgroups, our research did reveal potentially notable differences in their effect in size.

Furthermore, our findings indicate that students whose mothers have lower educational attainment, experience a more significant negative impact when not using digital devices during classroom lessons, unlike those with more educated mothers. This implies that parents with lower levels of education may struggle to provide alternative forms of academic support, making digital devices more crucial for academic success and imposing a greater penalty when not used. As previously mentioned, parents with higher education levels typically invest more time and resources in their children, such as ensuring access to better educational opportunities, possibly influenced by sorting.

Moving to academic achievement levels, we found that low-performance students exhibited a significant negative impact when not using digital devices during classroom lessons, while high-achieving students showed no significant impact. The positive effects of using digital devices during classroom lessons were significant for low-performance students. Possibly indicating that struggling students may derive greater benefit from additional support provided by technology, compared to high-achieving students that may already possess strong academic skills and thus require less support from technology. Additionally, limited access to educational resources outside the classroom may also contribute to these varying effects (Barrow et al., 2009).

### 6.4 Rising impact of digital device usage in education across the last decade

In our comparison of the impact of digital devices over time, spanning from 2009 to 2018, a noticeable increase in their influence is apparent. Our analysis in 2009, showed a positive, but modest impact on math test scores, this impact was significantly amplified by 2018. Although these findings suggest a continuous and substantial rise in the impact of digital devices on test scores, it's essential to consider this in light of the COVID-19 aftermath. Despite the growing prevalence of digital tools and their demonstrable impact, the integration of these tools during the pandemic was not universally seamless or efficient enough to substitute traditional education. This contradiction calls into question the way that technology is used in education and the necessity of a deliberate strategy for digital integration to ensure long-term success.

### 6.5 Limitations

Before summarizing this study, it is essential to acknowledge its limitations. The first limitation lies in the use of PISA, which restricts our examination to only be able to investigate the digital device usage for subjects, without delving deeper into how it is used for different tasks or the efficiency of students' usage. The PISA student questionnaire relies on self-reporting and students' perceptions of time spent on each subject, which may introduce inaccuracies. There is a possibility that students may not accurately report the efficient time they spent using digital resources, particularly due to potential distractions. According to OECD reports, approximately 30% of students report facing distractions while using digital devices (OECD, 2023).

Furthermore, our study's sample size is restricted to only 8 European countries, which poses challenges in generalizing the findings, especially considering the country-specific effects discussed earlier. It is likely that the impacts differ between developed and developing countries due to variations in ICT infrastructures and internet accessibility within each country. A broader sample encompassing a more diverse range of countries could have provided a more comprehensive understanding of the subject. However, our current sample provided us with a more homogenous group.

A common problem previous research has found is the endogeneity (Fernández-Gutiérrez et al., 2020), there are factors that influence both educational attainment and students' usage of ICT which are hard to capture. To address this, we used the correlated random effects model, aiming to account for unobserved school and student characteristics while also incorporating control variables such as family background and ICT. However, despite our efforts, there remain unobserved factors that may influence the results, posing challenges in establishing a causal relationship. Although our analysis leans towards description rather than causation, we still disclosed compelling insights regarding the relationship between ICT and educational achievements.

## 7. Conclusion

To summarize, our study has provided significant insights into the impact of digital device usage on educational achievement, revealing subject-specific effects and implications for various student groups. By investigating our research questions, we have gained a better understanding how digital devices affect test scores in various subjects and investigated how this impact has evolved over time.

Our findings highlight the importance of recognizing the multifaced ways in which digital devices impact learning outcomes, underscoring the need for tailored approaches that consider the various subjects and learning contexts. In line with previous studies, our findings on digital device usages impact are quite modest and depends on whether it used during the classroom lessons or outside, as well as the which specific subjects its applied to.

Additionally, our study reveals that students who do not use digital devices face a penalty, especially those from disadvantaged backgrounds or those who require additional support. Our findings emphasize the importance of taking socio-economic and other demographic factors into account when analyzing the impact of ICT on educational achievements. Future study efforts should delve deeper into investigating how different groups are affected by digital device usage, with a particular emphasis on promoting equity and addressing discrepancies in access and usage.

Although our study primarily focuses on data from 2018, it is important to acknowledge that this may not fully capture the evolving role of technology in education. Given the rapid advancements in artificial intelligence and interactive learning tools, future research should explore more recent data to assess how these developments influence the relationship between digital device usage and educational achievement. Furthermore, the profound disruptions caused by the COVID-19 pandemic highlight the importance of exploring how learning environments have evolved in this new digital era. While our study concentrates on pre-COVID-19 circumstances, it's crucial to also examine the post-pandemic landscape to understand how the influence of digital device usage has changed over time.

Additionally, while discussing the cost-benefit aspect of technology investments in education, it is necessary to explore the possible benefits of digital devices beyond educational accomplishments, such as their impact on innovative teaching and learning techniques. It would be interesting to further explore how early exposure to technology impacts people in later life and what the additional benefits would be, particularly in terms of workforce preparedness and digital literacy. Early technology integration in education may have positive effects in reducing the digital divide that exists in modern society.

In conclusion, this study contributes to the growing body of research on ICT integration in education and provides insightful information for researchers, educators, and policymakers. Our research revealed that the impact of digital devices on educational achievement is not exclusively determined by the level of usage, suggesting that the focus should rather be on the accessibility and quality of digital device usage. Further research is needed in this area as it's important to understand the complex dynamics of digital device usage in educational environments, enabling its optimal and efficient integration for positive learning outcomes.

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## Appendix

*TABLE A1*
*Descriptive statistics of test scores and control variables, 2018 sample*

| | *Mean (1)* | *Std. dev. (2)* | *Min (3)* | *Max (4)* |
|---|---|---|---|---|
| **Test scores** | | | | |
| Math | 498.7219 | 88.2243 | 139.428 | 801.935 |
| Science | 491.604 | 88.8370 | 121.321 | 862.623 |
| Read | 495.02333 | 92.6868 | 153.181 | 812.093 |
| Math ( Normalized) | 0 | 1 | -4.0725 | 3.4368 |
| Science ( Normalized) | 0 | 1 | -4.1681 | 4.1764 |
| Read (Normalized) | 0 | 1 | -3.6881 | 3.4208 |
| **Student Characteristics** | | | | |
| Female (female if = 1) | 0.4993 | 0.5000 | 0 | 1 |
| Age | 15.7847 | 0.2899 | 15.08 | 16.33 |
| Immigrant (if 1st and 2nd generation = 1) | 0.1073 | 0.3095 | 0 | 1 |
| Highest level of education completed by mother | 4.3880 | 1.5952 | 0 | 6 |
| Highest level of education completed by Father | 4.1882 | 1.6520 | 0 | 6 |
| More than 200 books at home | 0.2234 | 0.4165 | 0 | 1 |
| Student has its own room | 0.8017 | 0.3987 | 0 | 1 |
| Student attended pre-primary school for at least 2 years | 0.9297 | 0.2556 | 0 | 1 |
| Grade Repetition, if repeated a grade = 1 | 0.1587 | 0.3652 | 0 | 1 |
| Grade compared to modal grade in country | -0.1449 | 0.5323 | -3 | 2 |
| Positive attitude towards learning in School (want to learn as much as possible) | 0.4782 | 0.4995 | 0 | 1 |

*TABLE A1*
*(Continued)*

| | *Mean* (1) | *Std. dev.* (2) | *Min* (3) | *Max* (4) |
|---|---|---|---|---|
| **School Characteristics** | | | | |
| School Size | 763.1054 | 428.6554 | 7 | 2698 |
| Located in a rural area | 0.0417 | 0.1998 | 0 | 1 |
| Located in a small town | 0.2193 | 0.4131 | 0 | 1 |
| Located in a town | 0.4465 | 0.4971 | 0 | 1 |
| Located in a city | 0.1898 | 0.3921 | 0 | 1 |
| Located in a large city | 0.1014 | 0.3018 | 0 | 1 |
| Share of non-native speakers in school (%) | 13.5731 | 19.5835 | 0 | 100 |
| Instruction hindered by lack of physical infrastructure | 0.4471 | 0.4972 | 0 | 1 |
| Instruction hindered by lack of teaching staff | 0.2927 | 0.4550 | 0 | 1 |
| **ICT** | | | | |
| Availability of computer at home and student uses it (laptop or Desktop computer) | 0.8938 | 0.3080 | 0 | 1 |
| Availability Internet connection at home | 0.9582 | 0.2001 | 0 | 1 |
| If student uses digital devices at home for browsing the Internet for schoolwork (almost every day/everyday) | 0.2396 | 0.4268 | 0 | 1 |
| If the student use digital devices at home for browse material from your school's website (e.g. timetable or course materials) (almost every day/everyday) | 0.1751 | 0.3801 | 0 | 1 |

*Notes:* PISA sample 2018. Column (1)-(4) include mean, standard deviation, minimum value, and maximum value of the control variables. Control variables for ICT are included under the “Student Controls” in the regressions. The ICT variables are not related to specific subjects and are not the same variables that capture the usage of digital devices during and outside the classroom. The test scores are the plausible value 1 and normalized version.

*TABLE A2*

*Descriptive statistics of test scores and control variables, 2009 sample*

| | *Mean* (1) | *Std. dev.* (2) | *Min* (3) | *Max* (4) |
|---|---|---|---|---|
| **Test scores** | | | | |
| Math | 492.0269 | 92.023 | 48.07 | 803.25 |
| Science | 497.0407 | 92.8794 | 47.13 | 856.53 |
| Read | 492.8524 | 91.8654 | 6.65 | 815.04 |
| Math ( Normalized) | 0 | 1 | -4.8244 | 3.3819 |
| Science ( Normalized) | 0 | 1 | -4.8440 | 3.8705 |
| Read (Normalized) | 0 | 1 | -5.2925 | 3.5071 |
| **Student Characteristics** | | | | |
| Female (female if = 1) | 0.4940 | 0.5000 | 0 | 1 |
| Age | 15.7768 | 0.2924 | 15.23 | 16.33 |
| Immigrant (if 1st and 2nd generation = 1) | 0.0761 | 0.2652 | 0 | 1 |
| Highest level of education completed by mother | 3.8121 | 1.6502 | 0 | 6 |
| Highest level of education completed by Father | 3.7249 | 1.6884 | 0 | 6 |
| More than 200 books at home | 0.2255 | 0.4179 | 0 | 1 |
| Student has its own room | 0.7985 | 0.4011 | 0 | 1 |
| Student attended pre-primary school = 1 | 0.8262 | 0.3789 | 0 | 1 |
| Grade Repetition, if repeated a grade = 1 | 0.0275 | 0.1637 | 0 | 1 |
| Grade compared to modal grade in country | -0.2384 | 0.5882 | -3 | 2 |
| Positive attitude towards learning in School (want to learn as much as possible) | 0.4881 | 0.4998 | 0 | 1 |
| **School Characteristics** | | | | |
| School Size | 659.1322 | 369.9493 | 11 | 5362 |
| Located in a rural area | 0.0487 | 0.2153 | 0 | 1 |
| Located in a small town | 0.2199 | 0.4142 | 0 | 1 |
| Located in a town | 0.4303 | 0.4951 | 0 | 1 |
| Located in a city | 0.2141 | 0.4102 | 0 | 1 |
| Located in a large city | 0.0870 | 0.2818 | 0 | 1 |
| Share of non-native speakers in school | 0.24081 | 0.4276 | 0 | 1 |
| Instruction hindered by lack of teaching staff | 0.1611 | 0.3676 | 0 | 1 |

*Table A2*
*(continued)*

| | *Mean* *(1)* | *Std. dev.* *(2)* | *Min* *(3)* | *Max* *(4)* |
|---|---|---|---|---|
| **ICT** | | | | |
| Availability of computer at home and student uses it (laptop or Desktop computer) | 0.9403 | 0.2368 | 0 | 1 |
| Availability Internet connection at home | 0.8683 | 0.3382 | 0 | 1 |
| If student uses digital devices at home for browsing the Internet for schoolwork (almost every day/everyday) | 0.1375 | 0.3443 | 0 | 1 |
| If the student use digital devices at home for browse material from your school's website (e.g. timetable or course materials) (almost every day/everyday) | 0.0633 | 0.2436 | 0 | 1 |

*Notes:* PISA sample 2009. Column (1)-(4) include mean, standard deviation, minimum value, and maximum value of the control variables. Control variables for ICT are included under the “Student Controls” in the regressions. The ICT variables are not related to specific subjects and are not the same variables that capture the usage of digital devices during and outside the classroom. The test scores are the plausible value 1 and normalized version. Variable “Instruction hindered by lack of physical infrastructure” not existing in dataset.

TABLE A3

*Summary statistics of digital device usage by categorical variables, 2018 sample*

| | No time | | More than 60 minutes a week | |
|---|---|---|---|---|
| | Mean (1) | Std. Dev. (2) | Mean (3) | Std. Dev. (4) |
| **Math** | | | | |
| Using digital devices during classroom lessons | 0.63814 | 0.4805 | 0.1087 | 0.3112 |
| Using digital devices outside of classroom lessons | 0.5283 | 0.4992 | 0.0812 | 0.2732 |
| **Science** | | | | |
| Using digital devices during classroom lessons | 0.5511 | 0.4974 | 0.1263 | 0.3322 |
| Using digital devices outside of classroom lessons | 0.4631 | 0.4986 | 0.0917 | 0.2886 |
| **Read** | | | | |
| Using digital devices during classroom lessons | 0.5774 | 0.4940 | 0.1151 | 0.3191 |
| Using digital devices outside of classroom lessons | 0.4358 | 0.4959 | 0.0904 | 0.2867 |

*Notes:* PISA sample 2018. Mean and standard deviation of digital device use during and outside classroom lessons in the respective subject. In column (1)-(2): students that does not use digital devices. In column (3)-(4): students who uses digital devices for more than 60 minutes a week. Observations: 59,604.

TABLE A4

*Summary statistics of digital device usage by categorical variables, 2009 sample*

| | No time | | More than 60 minutes a week | |
|---|---|---|---|---|
| | Mean (1) | Std. Dev. (2) | Mean (3) | Std. Dev. (4) |
| **Math** | | | | |
| Using digital devices during classroom lessons | 0.8061 | 0.3954 | 0.0306 | 0.1722 |
| **Science** | | | | |
| Using digital devices during classroom lessons | 0.8303 | 0.3754 | 0.0216 | 0.1455 |
| **Read** | | | | |
| Using digital devices during classroom lessons | 0.8350 | 0.3712 | 0.0269 | 0.1619 |

*Notes:* PISA sample 2009. Mean and standard deviation of digital device use during and outside classroom lessons in the respective subject. In column (1)-(2): students that does not use digital devices. In column (3)-(4): students who uses digital devices for more than 60 minutes a week. Observations: 82,828.

TABLE A5

*Summary statistics of ICT usage and student achievements, by country in 2009 and 2018 sample*

| | *Computers at school* | *ICT during classroom lessons* | *ICT outside of classroom lessons* | *Between-subject variation* | *Math test scores* | *Std. Dev.* | *Science test scores* | *Std. Dev* | *Read test scores* | *Std. Dev.* | *Observations* | *Number of Schools* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* | *(7)* | *(8).* | *(9)* | *(10)* | *(11)* | *(12)* |
| **Belgium** | | | | | | | | | | | | |
| 2009 | 0.6252 | 1,1554 | - | 0.1424 | 525.2864 | 98.586 | 518.2938 | 95.2493 | 516.0446 | 95.3489 | 7 931 | 262 |
| 2018 | 0.6571 | 1.6027 | 1,6385 | 0,2584 | 527.0107 | 88.7348 | 520.9018 | 90.8513 | 514.0338 | 94.7949 | 6 513 | 267 |
| **Denmark** | | | | | | | | | | | | |
| 2009 | 0.9206 | 1,6828 | - | 0.47261 | 505.7348 | 86.1588 | 502.1802 | 90.5491 | 497.5345 | 82.1588 | 5 550 | 285 |
| 2018 | 0.7053 | 3,3575 | 2,4679 | 0,3720 | 520.88 | 78.3035 | 505.1809 | 85.943 | 515.0996 | 86.1436 | 6 031 | 341 |
| **Finland** | | | | | | | | | | | | |
| 2009 | 0.8652 | 1,2947 | - | 0.29218 | 542.0317 | 81.0073 | 555.5344 | 87.6909 | 537.28 | 85.2704 | 5 611 | 203 |
| 2018 | 0.8946 | 1,7519 | 1,6081 | 0,3260 | 5.173513 | 78.5543 | 530.8259 | 90.4922 | 532.9824 | 92.7813 | 4 707 | 204 |
| **Greece** | | | | | | | | | | | | |
| 2009 | 0.5823 | 1,3280 | - | 0.1354 | 468.0155 | 88.3797 | 471.6684 | 90.6721 | 484.4089 | 94.9193 | 4 784 | 184 |
| 2018 | 0.7598 | 1,4262 | 1,6134 | 0,2191 | 462.9338 | 85.5704 | 465.6499 | 82.7344 | 473.362 | 92.5311 | 5 140 | 238 |
| **Ireland** | | | | | | | | | | | | |
| 2009 | 0.6227 | 1,1715475 | - | 0.1637 | 490.9357 | 83.8926 | 512.2191 | 94.7725 | 500.4421 | 93.1653 | 3 685 | 142 |
| 2018 | 0.6258 | 1,5436515 | 1,608129 | 0,2900 | 504.1468 | 76.4630 | 502.8622 | 86.9184 | 525.1475 | 88.8100 | 4 859 | 157 |

Table A5

(Continued)

| | *Computers at school* | *ICT during classroom lessons* | *ICT outside of classroom lessons* | *Between-subject variation* | *Math test scores* | *Std. Dev.* | *Science test scores* | *Std. Dev* | *Read test scores* | *Std. Dev.* | *Observations* | *Number of Schools* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* | *(7)* | *(8).* | *(9)* | *(10)* | *(11)* | *(12)* |
| **Italy** | | | | | | | | | | | | |
| 2009 | 0.6361 | 1,3566 | - | 0.3025 | 485.7951 | 91.8299 | 492.2458 | 94.9177 | 489.3113 | 94.1209 | 29 953 | 1 095 |
| 2018 | 0.6327 | 1,7516 | 1,8967 | 0,3425 | 499.9244 | 88.8927 | 481.595 | 85.6672 | 492.2221 | 91.2876 | 9 168 | 529 |
| **Spain** | | | | | | | | | | | | |
| 2009 | 0.6545 | 1,2047 | - | 0.1733 | 485.7717 | 89.05 | 491.1702 | 85.4924 | 483.6412 | 85.7176 | 25 034 | 889 |
| 2018 | 0.6548 | 1,6836 | 1,7948 | 0,3560 | 490.7095 | 88.2121 | 492.7975 | 89.4813 | 484.1667 | 90.9154 | 25 561 | 1 087 |
| **Iceland** | | | | | | | | | | | | |
| 2009 | 0.7918 | 1,3354 | - | 0.2980 | 508.9239 | 87.4140 | 497.1196 | 92.6855 | 502.6064 | 93.5227 | 3 519 | 131 |
| 2018 | 0.7880 | 2,1320 | 1,8273 | 0,3295 | 505.3473 | 86.6910 | 483.1574 | 88.1897 | 485.534 | 98.8317 | 2 636 | 138 |

*Notes:* Sample of PISA 2009 and 2018. Column (1) refers to share of student that has access to a computer and uses it in school. Column (2)-(3) uses the average of math and science. (2)-(3): Mean of usage of digital devices (ICT) in and outside of the classroom lessons (1 = no time, 2 = 0-30 minutes a week, 3 = 31-60 minutes a week, 4 = more than 60 minutes a week). Column (3) only have data from 2018. (4): Share of students that have differences in usage of digital devices between math's and science. For 2018, average of both during classroom lessons and outside and for 2009 only during classroom lessons. (5)-(10): average and standard deviation of PISA test scores in math, science and reading. (11)-(12): Number of student observations and number of schools. Total observations in 2018 is 59,604 and for 2009 it is 82,828.

TABLE A6

*Comparison of the within-student between-subject estimation for 2009 and 2018*

| | 2009 | | | | 2018 | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | | (2) | | (3) | | (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | 0.0091* | 0,0020 | 0.0091* | 0.0027 | 0.0275*** | 0.0097 | 0.0263*** | 0.0087 |
| | [3.33] | [0.20] | [3.39] | [0.35] | [16.68] | [2.47] | [15.47] | [2.01] |
| $\beta_{math} - \beta_{sci}$ | 0.0071 | | 0.0064 | | 0.0178*** | | 0.0176*** | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | No | | Yes | | No | | Yes | |
| Observations | 82.828 | | 82.828 | | 59.602 | | 59.602 | |
| Clusters | 3.068 | | 3.068 | | 2.691 | | 2.691 | |
| $R^2$ | 0.2691 | 0.2531 | 0.2834 | 0.2718 | 0.2264 | 0.2026 | 0.2406 | 0.2099 |

*Notes:* PISA 2009 and 2018 sample. Dependent variable: PISA student test scores in math and science. Test scores and the variable for the usage of digital devices has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 and A2 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A7

*Comparison of the within-student between-subject estimation for 2009 and 2018, by different category of usage*

| | 2009 | | | | 2018 | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons Implied $\beta^S$ | -0.0297* [6.58] | -0.0107 [0.88] | 0.0185 [0.66] | 0.0219 [0.55] | -0.0495*** [16.70] | -0.0066 [0.35] | 0.0382* [3.56] | 0.0070 [0.16] |
| $\beta_{maths} - \beta_{science}$ | -0.0190 | | -0.0035 | | -0.0429*** | | 0.0311* | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 82.828 | | 82.828 | | 59.602 | | 59.602 | |
| Clusters | 3.068 | | 3.068 | | 2.691 | | 2.691 | |
| $R^2$ | 0.2828 | 0.2715 | 0.2826 | 0.2710 | 0.2406 | 0.2106 | 0.2412 | 0.2091 |

*Notes:* PISA 2009 and 2018 sample. Dependent variable: PISA student test scores in math and science, test scores has been normalizedto mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 and A2 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A8

*Within-student between-subject estimation, by country for 2018 sample*

| | Belgium (1) | | Denmark (2) | | Finland (3) | | Iceland (4) | |
|---|---|---|---|---|---|---|---|---|
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.01963** | 0.0109 | -0.0184 | -0.0273 | 0.0381*** | 0.0038 | -0.0073 | -0.0089 |
| | [4.24] | [1.04] | [1.59] | [2.53] | [7.21] | [0.07] | [0.21] | [0.26] |
| $\beta_{math} - \beta_{sci}$ | -0.0305*** | | 0.0089 | | 0.0343** | | 0.0016 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.0291** | -0.0026 | 0.0305** | -0.0051 | 0.0381** | 0.0144 | 0.0097 | -0.0372 |
| | [6.07] | [0.05] | [4.38] | [0.13] | [4.28] | [0.80] | [0.40] | [5.07]** |
| $\beta_{math} - \beta_{sci}$ | -0.0265*** | | 0.0356 | | 0.0237 | | 0.0470*** | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 6.194 | | 4.666 | | 4.611 | | 2.605 | |
| Clusters | 252 | | 256 | | 200 | | 126 | |
| $R^2$ | 0.3826 | 0.3646 | 0.1853 | 0.1865 | 0.1905 | 0.2034 | 0.1585 | 0.1602 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and science. Test scores and the two variables in table has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A9

*Within-student between-subject estimation, by country for 2018 sample*

| | Greece (1) | | Ireland (2) | | Italy (3) | | Spain (4) | |
|---|---|---|---|---|---|---|---|---|
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | 0.0103 | -0.0184 | 0.0051 | 0.0002 | 0.0257* | -0.0055 | -0.0045 | 0.0226*** |
| | [0.27] | [1.62] | [0.16] | [0.00] | [3.30] | [0.17] | [0.28] | [8.20] |
| $\beta_{math} - \beta_{sci}$ | 0.0286* | | 0.0050 | | 0.0311** | | -0.0270*** | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | 0.0115 | 0.0176 | -0.0033 | 0.0058 | -0.0171 | 0.0069 | 0.0127 | 0.0181** |
| | [0.37] | [1.13] | [0.09] | [0.22] | [1.77] | [0.35] | [2.41] | [3.92] |
| $\beta_{math} - \beta_{sci}$ | -0.0060 | | -0.0092 | | -0.0240* | | -0.0054 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 5.034 | | 4.612 | | 8.648 | | 23.232 | |
| Clusters | 233 | | 149 | | 489 | | 986 | |
| $R^2$ | 0.2316 | 0.2137 | 0.1853 | 0.1865 | 0.2079 | 0.19 | 0.3806 | 0.3290 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and science. Test scores and the two variables in table has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A10

*Within-student between-subject estimation by North and South European countries, 2018 sample*

| | Nordics (1) | | South (2) | |
|---|---|---|---|---|
| | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | |
| Implied $\beta^S$ | 0.0503*** | -0.0414*** | 0.0308*** | 0.0122 |
| | [23.21] | [13.19] | [11.23] | [2.47] |
| $\beta_{math} - \beta_{sci}$ | 0.0916*** | | 0.0186** | |
| Using digital devices outside of classroom lessons | | | | |
| Implied $\beta^H$ | 0.0491*** | 0.0038 | 0.0053 | 0.0126* |
| | [19.21] | [0.13] | [0.40] | [2.83] |
| $\beta_{math} - \beta_{sci}$ | 0.0453*** | | -0.0073 | |
| Student controls | Yes | | Yes | |
| School controls | Yes | | Yes | |
| Observations | 11.882 | | 36.914 | |
| Clusters | 582 | | 1.708 | |
| $R^2$ | 0.1684 | 0.1861 | 0.2376 | 0.2096 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and science. Test scores and the two variables in table has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A11

*Within-student between-subject estimation for different subjects' pairs, 2018 sample*

| | "Math & Read" (1) | | "Read & Science" (2) | |
|---|---|---|---|---|
| | Math | Read | Read | Science |
| Using digital devices during classroom lessons | | | | |
| Implied $\beta^S$ | 0.0142** | -0.074 | -0.0004 | 0.0089 |
| | [4.11] | [1.09] | [0.00] | [2.09] |
| $\beta_{math} - \beta_{read}$ | 0.0215*** | | 0.0235* | |
| Using digital devices outside of classroom lessons | | | | |
| Implied $\beta^H$ | 0,0057 | 0.0204*** | 0.0247*** | 0.0107* |
| | [0.85] | [8.65] | [17.85] | [3.35] |
| $\beta_{math} - \beta_{read}$ | -0.0147** | | 0.0139** | |
| Student controls | Yes | | Yes | |
| School controls | Yes | | Yes | |
| Observations | 59.602 | | 59.602 | |
| Clusters | 2.691 | | 2.691 | |
| $R^2$ | 0.2451 | 0.2352 | 0.2306 | 0.2101 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and read as well as read & science. Test scores and the two variables in table has been normalized to mean 0 and SD 1. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

Table A12

*Within-student between-subject estimation depending on different digital device usage, by country for 2018 sample*

| | Belgium | | | | Denmark | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | 0.0240 | -0.02477 | -0.0847*** | 0.0673** | -0.02155 | 0.08756* | -0.1357 | -0.0237 |
| | [1.51] | [1.55] | [8.34] | [5.36] | [0.16] | [2.82] | [0.27] | [075] |
| $\beta_{maths} - \beta_{science}$ | 0.04879** | | -0.1521*** | | -0.1091* | | 0.0100 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | 0.06344*** | 0.0136 | 0.0339 | 0.0406 | -0.0665* | 0.0348 | 0.0354 | -0.0157 |
| | [10.24] | [0.46] | [0.50] | [0.63] | [3.47] | [0.46] | [0.88] | [0.14] |
| $\beta_{maths} - \beta_{science}$ | 0.0499*** | | -0.0067 | | -0.1013*** | | 0.0511 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 6.194 | | 6.194 | | 4.666 | | 4.666 | |
| Clusters | 252 | | 252 | | 256 | | 256 | |
| $R^2$ | 0.3823 | 0.3643 | 0.3821 | 0.3677 | 0.1699 | 0.1715 | 0.1834 | 0.1815 |

*Notes:* PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The results present country specific effects for Belgium (column (1)-(2)) and Denmark (column (3) –(4)).Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

Table A13

*Within-student between-subject estimation depending on different digital device usage, by country for 2018 sample*

| | Finland | | | | Iceland | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0553** | 0.0048 | 0.1091** | 0.0561 | -0.0058 | 0.0561* | 0.0009 | 0.0265 |
| | [6.36] | [0.05] | [4.37] | [1.10] | [0.06] | [3.25] | [0.00] | [0.54] |
| $\beta_{maths} - \beta_{science}$ | -0.0601** | | 0.0529 | | -0.0618** | | -0.0256 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.0659** | -0.0037 | 0.0456 | 0.0824 | -0.0230 | 0.0716*** | 0.0265 | -0.0781 |
| | [5.83] | [0.02] | [0.26] | [1.18] | [0.83] | [6.72] | [0.21] | [2.04] |
| $\beta_{maths} - \beta_{science}$ | -0.0622*** | | -0.0367 | | -0.0946*** | | 0.1045** | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 4.611 | | 4.611 | | 2.605 | | 2.605 | |
| Clusters | 200 | | 200 | | 126 | | 126 | |
| $R^2$ | 0.1873 | 0.2026 | 0.1790 | 0.1870 | 0.1575 | 0.1610 | 0.1556 | 0.1546 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The results present country specific effects for Finland (column (1)-(2)) and Iceland (column (3) –(4)).Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

Table A14

*Within-student between-subject estimation depending on different digital device usage, by country for 2018 sample*

| | Greece | | | | Ireland | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.01187 | 0.04927* | 0.0137 | -0.0417 | -0.0145 | 0.0130 | 0.0201 | 0.0152 |
| | [0.12] | [3.53] | [0.05] | [0.87] | [0.45] | [0.36] | [0.21] | [0.10] |
| $\beta_{maths} - \beta_{science}$ | -0.0611** | | 0.0554 | | -0.0275 | | 0.0050 | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.01383 | -0.0322 | 0.0785 | 0.0730 | 0.0075 | -0.0241 | -0.0308 | -0.0155 |
| | [0.23] | [1.41] | 1.08] | [1.10] | [0.15] | [1.64] | [0.49] | [0.09] |
| $\beta_{maths} - \beta_{science}$ | 0.0184 | | 0.0054 | | 0.0316 | | -0.0153 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 5.034 | | 5.034 | | 4.612 | | 4.612 | |
| Clusters | 233 | | 233 | | 149 | | 149 | |
| $R^2$ | 0.2376 | 0.2209 | 0.2155 | 0.1931 | 0.1942 | 0.1868 | 0.1943 | 0.1869 |

*Notes*: PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The results present country specific effects for Greece (column (1)-(2)) and Ireland (column (3) –(4)).Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6.The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

Table A15

*Within-student between-subject estimation depending on different digital device usage, by country for 2018 sample*

| | Italy | | | | Spain | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Science | Math | Science | Math | Science | Math | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0522** | 0.02960 | 0.0216 | -0.0307 | 0.0038 | -0.0580*** | -0.0502* | 0.0348 |
| | [4.58] | [1.79] | [0.25] | [0.55] | [0.05] | [14.32] | [3.09] | [2.35] |
| $\beta_{maths} - \beta_{science}$ | -0.08176*** | | 0.0523 | | 0.0618*** | | -0.0850*** | |
| Using digital devices outside of classroom lessons | | | | | | | | |
| Implied $\beta^H$ | 0.02451 | 0.0107 | -0.0529 | 0.0386 | -0.0190 | -0.0633*** | -0.0069 | -0.0165 |
| | [1.14] | [0.23] | [1.36] | [0.86] | [1.66] | [17.46] | [0.04] | [0.26] |
| $\beta_{maths} - \beta_{science}$ | 0.0138 | | -0.0915** | | 0.0443*** | | 0.0096 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 8.648 | | 8.648 | | 23.232 | | 23.232 | |
| Clusters | 489 | | 489 | | 986 | | 986 | |
| $R^2$ | 0.2052 | 0.1998 | 0.2038 | 0.1944 | 0.3795 | 0.3292 | 0.3761 | 0.3210 |

*Notes:* PISA 2018 sample. Dependent variable: PISA normalized student test scores in math and science. The results present country specific effects for Italy (column (1)-(2)) and Spain (column (3) –(4)).Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6. The implied β is the estimated effect that using digital devices during and outside the classrooms lessons has on math and science, depending on the different time usage "No time" or "More than 60 minutes a week)". "No time": no usage of digital devices in both science and math. "More than 60 minutes a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied β has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.

TABLE A16

*Within-student between-subject estimation depending on different digital device usage for other pair of subjects, 2018 sample*

| | "Math & Read" | | | | " Read & Science" | | | |
|---|---|---|---|---|---|---|---|---|
| | No time (1) | | More than 60 min a week (2) | | No time (3) | | More than 60 min a week (4) | |
| | Math | Read | Math | Read | Read | Science | Read | Science |
| Using digital devices during classroom lessons | | | | | | | | |
| Implied $\beta^S$ | -0.0284** | 0.0052 | 0.0346* | -0.0313 | -0.0105 | -0.0090 | -0.0206 | 0.0203 |
| | [4.49] | [0.19] | [3.27] | [2.56] | [0.98] | [0.70] | [1.61] | [1.53] |
| $\beta_{maths} - \beta_{Read}$ | -0.0336** | | 0.0659*** | | -0.0015 | | -0.0409** | |
| Using digital devices outside classroom lessons | | | | | | | | |
| Implied $\beta^H$ | -0.0082 | -0.0375*** | 0.0228 | 0.0369 | -0.0384*** | -0.0102 | 0.0344* | 0.0215 |
| | [0.52] | [8.45] | [0.90] | [2.52] | [15.13] | [1.08] | [3.15] | [1.10] |
| $\beta_{maths} - \beta_{Read}$ | 0.02933** | | -0.0142 | | -0.0282*** | | 0.0129 | |
| Student controls | Yes | | Yes | | Yes | | Yes | |
| School controls | Yes | | Yes | | Yes | | Yes | |
| Observations | 59.602 | | 59.602 | | 59.602 | | 59.602 | |
| Clusters | 2,691 | | 2,691 | | 2,691 | | 2,691 | |
| $R^2$ | 0.2430 | 0.2347 | 0.2439 | 0.2330 | 0.2296 | 0.2079 | 0.2327 | 0.2120 |

*Notes:* PISA 2018 sample. Dependent variable: PISA student test scores in math and read and read and science. The test scores have been normalized to mean 0 and SD 1. In column (1)-(2) math and read has been used and in column (3)-(4) read and science. Correlated random effects models is estimated by seemingly unrelated regressions (SUR), according to equations 5 and 6 however now with new pairs of subjects. The implied $\beta$ is the estimated effect that using digital devices during and outside the classrooms lessons has on the subjects, depending on the different categories "No time" or "More than 60 minutes a week". "No time": no usage of digital devices in both science and math. " More than 60 min a week": using it for more than 60 minutes a week in both math and science. The coefficient for the implied $\beta$ has been calculated according to equation 7 and 8. The regression results have been adjusted for sampling probability, applying weights derived from the survey design. See table A1 in the appendix for controls variables for student and school. The $\chi^2$ statistic for the tests are shown in the brackets. Robust standard errors are adjusted for clustering at the school level. Significance levels: *10%, **5%, ***1%.