The different effects of digital devices on students' motivation

Evidence from the United States

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Abstract

The usage of computers in classrooms is becoming increasingly common in the US. Digital devices are gaining more and more relevance for teachers and their students. This study uses the TIMSS 2015 data to examine the impact of using digital tools in classrooms. To capture these effects, we use a fixed effect model and exploit the variation between the subjects maths and science. While we find only small effects on students' overall achievement and cognitive skills, positive and significant effects are observed for students' motivation. Further, we examine heterogeneous effects by gender, number of devices the students have at home and by the students' socioeconomic background. We cannot find significant differences between genders and the number of available devices, but differences by students' socioeconomic status (SES) are proven to be significant, with stronger effects for low SES students.

Keywords: Education, Digital devices, TIMSS, Between – subject variation, Motivation

Contents

1. Introduction

Nowadays, politics, parents and students have begun to particularly focus on the impact of students' computer use at school and at home on their academic performance. It is widely discussed how the increased integration of digital devices in education systems could improve schools.

In recent years, governments have strongly promoted the implementation of computer use in classrooms (Thomas, 2016). Living in a world with an increasing relevance of technology, new opportunities open up for education systems. This raises the attention towards the need and the chance to use computers and tablets as important instruments to improve learning experiences. With digital devices, schools could be more flexibly and could support teachers and their students. Students are confronted with an increasing use of digital devices to follow online lectures, submit assignments and keep in contact with teachers and classmates.

By using data of the 2015 wave of the Trends in International Mathematics and Science Study (TIMSS), we study the effect of using digital devices in classrooms on students' achievements, their cognitive skills and their motivation. TIMSS is a cross – national survey following trends in mathematics (maths) and science of fourth and eighth grade students and collects a wide range of variables in the context of education. Our focus lies on the eighth grade sample of the United States (US).

The impact of digital tools in the classroom is not sufficiently understood and can be potentially ambiguous. On the one hand, the effective integration of technology into classrooms could improve students' overall test scores and their cognitive skills. By using technology, students might learn skills faster and have a better chance to practice them. Digital tools could enhance problem – solving and critical – thinking skills. Moreover, by integrating playful activities, such as computer games, digital devices might act as a motivator or a coach for students. By integrating digital tools in classrooms, teachers could have the possibility to establish more diversified teaching practices. These effects might differ depending on students' gender, their socioeconomic background and the availability of digital devices at home. As male students are often more familiar with the use of computers, the integration of digital devices could have a stronger effect for them (Shashaani, 1993). Often males spent more time playing digital games than females, whereas females associate digital tools primarily with communication and educational assistance (Weiser, 2000). Further, the flexible level of learning speed and difficulty might especially enhance more disadvantaged students, since the learning materials can be designed more individually (Falck et al., 2018).

On the other hand, there are several risks, for instance that students are getting distracted more easily or teachers are missing adequate training to use digital tools effectively (Adler & Benbunan-Fich, 2013; Belo et al., 2014; Gupta & Irwin, 2016; United Nations Educational & Cultural Organization, 2008). Furthermore, the respectable use of digital tools already requires skills, such as basic cognitive knowledge, critical thinking or self – discipline which are often more represented by students with a higher socioeconomic status (SES) (Falck et al., 2018). Hence, students with more available digital information devices at home might benefit more from integrating digital tools in classrooms (Falck et al., 2018).

To estimate the causal effect of digital devices on learning outcomes, one would ideally randomly assign different types of computer use to students. However, in the observational data we use, digital teaching is not randomly assigned, as for instance students with high inherent ability are likely to self – select into schools and classrooms which make more use of information technology. A naive OLS estimator would thus be biased. We overcome this likely source of bias by using a student fixed effects approach that has been established in previous studies on teaching practices (Bietenbeck, 2014; Dee, 2005, 2007; Schwerdt & Wuppermann, 2011). Our empirical model exploits the quasi – panel structure of the TIMSS data. Students are tested twice, once in maths, once in science. We thus gain a causal estimator by using the within – student between – subject variation of computer use in classrooms. Thereby, we contribute to the existing literature by investigating the influence of digital devices on students' achievement, cognitive skills and motivation using a school, subject and student fixed effects approach. Our variable of interest "Digital tools" covers the use of digital devices during the class by the teacher.

We only find small and statistically insignificant effects of technology use on overall test scores. Going from no or almost no computer use at all to a every or almost every day computer use increases the students' overall achievement by 2.76 – 8.28 percent of a standard deviation. These effect sizes are small to modest, compared for example with estimators of 10 – 15 percent of a standard deviation in the measurement of teacher value added (Hanushek & Rivkin, 2010) and on average 25 - 30 percent of a standard deviation learning outcome of a student in one school year (Woessmann, 2016). By contrast, we find strong evidence that the use of computers and tablets in the classroom raises students' motivation. We find that an increase from using no or almost no digital tools at all to a daily use increases the reference of the students' favorite subject by 10.64 – 13.11 percent of a standard deviation.

We further investigate heterogeneous effects by gender, number of devices at home and SES. While we cannot find significant differences between genders and number of devices available at home, we extrapolate stronger effects for students from a low SES background. Overall, we find positive effects on students' motivation in all studied subgroups. This corresponds with the ambition of the US Department of Education to promote a growth mindset of students, to stimulate students' motivation and enthusiasm about the subject studied (Thomas, 2016). We argue that these findings on increased motivation could affect students long run education prospects.

This paper is organized as follows: The paper begins with an overview of the relevant literature in section 2, which is followed by a short introduction to the education system of the US in section 3. In section 4 we describe the data we use for our analysis. Thereafter, our empirical framework is presented in section 5. Section 6 presents the results of our analysis, which is followed by a discussion in section 7. Finally, section 8 concludes.

2. Literature

In the last decades, several studies have tried to explain the role of digital devices at home, in schools and in classrooms. The different effects of technology in classrooms are subject to research since computers first appeared in classrooms in the 1980's (Cuban, 1986). The literature shows mixed results for the effect of technology use on students' achievement. The different results might be due to the complexity of digital tools, their usage and the various outcomes, such as test scores, cognitive skills or students' motivation. Researchers tried to evaluate the sign and effect sizes of the use of educational technology in classrooms.

Some previous studies find significant positive effects of computer use in school on students' achievement (Bakar et al., 2010; Brusic, 1991; Lin, 2008; Lowther et al., 2003; Tüzün et al., 2009). However, these studies mostly examine effects for small – scaled experiments within schools or districts. In addition, the programs they look at usually combine the implementation of computer use in classrooms with other factors such as teacher training and a change in teaching practices. For example, Lowther et al. (2003) examine the impact of a program which promoted computer use in schools but also provided specific teacher training. They find positive effects on students' achievement in a sample of 21 classrooms in the US. The positive effects could here be explained by other factors than digital tools, such as the teacher training and changed teaching practices. Significant positive effects can also be found in studies which use control strategies (Pagani et al., 2016; Wenglinsky, 1998).

In contrast, studies with causal effects estimators find little to no effects of technology use in classrooms on students' test scores (Comi et al., 2017; Falck et al., 2018; Rouse & Krueger, 2004; Woessmann & Fuchs, 2004). Some researchers even find negative effects (Angrist & Lavy, 2002; Papanastasiou et al., 2005). It is argued that these negative effects arise because students might be distracted by the complexity of computers. Further, since students might not be able to distinguish correct from incorrect information on the internet, they may use information from unreliable sources which negatively affects their learning outcomes (Aagaard, 2015; Douglas et al., 2012). Given the considerable advancements of technology over the last 30 years, one could expect more recent studies to show more positive effects of digital learning. However, such a pattern cannot be found in the literature, in fact effect sizes decreased in more recent studies (Cheung & Slavin, 2013).

An international comparison of the results further indicates differences between developed and developing countries. Falck et al. (2018) find positive effects in developing countries while the estimators for OECD countries are insignificant. Examining the implementation of a learning program in India, Banerjee et al. (2007) find positive effects on students' achievements.

A small group of studies further examines the effects of technology use in school by different subgroups of students. These heterogeneous effects are typically investigated by gender and SES. Given the widening education gap between males and females with boys falling behind (DiPrete & Buchmann, 2013), it is of interest to examine the effect technology has in this context. Previous studies provide evidence that male students gain more from computer use in teaching than their female counterparts (Pagani et al., 2016; Vekiri & Chronaki, 2008). In addition, heterogeneous effects by the socioeconomic background of students have been studied to make a contribution to the ongoing debate about equality in the education system (Coleman, 2019; Hufe et al., 2018; Schmidt et al., 2009). Though, studies show mixed results with both evidence that technology could work as an equalizer but also as a multiplier of inequalities. Pagani et al. (2016) find a higher effect on academic performance in reading and maths for students from low SES backgrounds in Italy. Contrary, at the international level, Falck et al. (2018) find higher effects of technology use in classrooms for children from high SES families.

Moreover, policymakers have claimed that digital learning fosters students' motivation and thus should be widely implemented to promote a positive mindset of students towards education. In their strategy papers on educational policy development, the US Department of Education states that one of the goals of digital learning is to improve students' motivation and enthusiasm about the subject studied (Department–of–Education–Office–of–Technology, 2010; Dweck, 2015; Thomas, 2016). Though, there exists only a small literature on how the use of technology in the classroom affects students' motivation. Lin (2008) shows that students who participated in web – based instructions exhibited a significantly better attitude towards maths. There is also evidence that the integration of digital devices affects fifth grade students' interest in science positively (Brusic, 1991). Using an experimental design, Bakar et al. (2010) also find that including technology in teaching and learning could improve students' motivation. However, Brusic (1991) shows that the positive effect on students' curiosity is not reflected in the science test score. All these studies examine the effect on students' motivation only for small – scaled experiments.[1] We contribute to the existing literature by studying the effect of digital learning on students' motivation using observational data from the US.

Inspired by previous studies, we investigate the influence of digital tools on students' achievement, their cognitive skills and their motivation using a within – student between – subject fixed effects approach. Further, different impacts by gender, number of devices at home and SES are studied. Given the results from previous studies which examined the effect of computers in classrooms in OECD countries with causal estimators, we expect

[1] Lin (2008) studies the effects on 132 students in two schools in Taiwan, Brusic (1991) studies 123 students in the US and Bakar et al. (2010) evaluate the effects on students in one school in Malaysia.

to find only small or even insignificant effects on students' achievement. However, we contribute to the existing literature by applying the fixed effects approach to study the impact on students' motivation and inherent heterogeneous effects.

3. Background

We conduct our analysis with the TIMSS data for the United States. We examine our study for the US to ensure comparability with other studies in the relevant literature which are mostly focused on the US. Further, the TIMSS data for the US provides a sufficiently large sample because technology availability in schools is widely common. Computer use in classrooms has been promoted by the US government already since the 1980's, which will be further explained later in this chapter.

Education in the United States is decentrally organized. Every state has its own department of education to define state – specific standards and regulations. Home, private or public education is compulsory over an age range, depending on each state throughout the US. 90% of students in elementary and secondary education attend public schools, 10% attend private schools (Mullis et al., 2016). Children usually enter preschool at the age of 3 or 4, followed by attending a kindergarten from age 5. Afterwards, children enter primary education by attending an elementary school from grade 1 to 5. The subsequent secondary education consists of middle – and high school. Children enter a middle school at age 10 and attend this school type from grade 6 to 8. The students tested in TIMSS eighth grade sample are thus attending middle school and are between 12 and 13 years old.[1] Education in middle school is followed by 4 years of high school from grade 9 to 12. Students usually finish high school at age 17 or 18. After completing high school, students can continue their education by attending colleges and universities (Mullis et al., 2016).

The use of computers in classrooms is becoming increasingly common, especially in the subjects maths and science. According to the National Center of Education Statistics (NCES), almost all public schools in the US have access to internet and use digital devices frequently nowadays (Gray et al., 2010).

[1] We do not include " age " in our descriptive tables (4.1, A.1) since in the open – access TIMSS data set information about the students' age are not provided.

The US government started to promote the use of computers in schools in 1996 by launching ”Americas technology literacy challenge” (Riley et al., 1996). This was the first national plan to encourage the nationwide use of technology in classrooms and to improve access to computers for schools. In the beginning of the 21st century, new technologies became increasingly important in the global economy. Education policy in the US was thus focused on transforming teaching to meet the needs of the highly competitive labor market. Schools were supported to implement technology use in classrooms and to provide students with information technology skills (Department–of–Education, 2000; Paige et al., 2004). The subjects maths and science were emphasized as being particularly important for the global competitiveness of the economy. Therefore, government initiatives supported the use of technology in these subjects to improve students' achievements (Department–of–Education–Office–of–Technology, 2010). In addition to the overall achievement of students, the Department of Education identifies technology in the classroom as a tool to promote a growth mindset of students (Dweck, 2015; Thomas, 2016). The intention is to stimulate students' motivation and enthusiasm about the subject studied which is expected to improve achievements and long run prospects. Further, the so called Enhancing Education through technology (Ed-Tech) State Program of 2015 supports State educational agencies (SEAs) with grants to improve the access to technology (Department–of–Education, 2004). The program aims at developing curricula and teacher training to promote the usage of information technology in classrooms.

All these support programs are likewise introduced at federal level. However, the implementation of digital infrastructure, teacher training, as well as adjustments of curricula, takes place at state level (Department–of–Education, 2004). The extent of digital learning also differs at school level. Differences arise due to differing ambitions of the principals to implement digital learning, as well as varying potentials to collect external funding for digital infrastructure (Thomas, 2016). The state programs mentioned above provide schools with some funding to promote digital learning. Nonetheless, usually additional funding is necessary to ensure adequate teacher training and digital infrastructure (Department–of–Education–Office–of–Technology, 2010). In addition, the intensity and the way of using computers in classrooms is finally decided by each teacher individually. Therefore, variation of technology use in classrooms can be observed even within schools.

The US government continues to promote technology use in classrooms to improve digital learning in the future. The National Education Technology Plan of 2016 (Thomas, 2016) focuses on the potential of technology in school to improve equality in education. By improving the access to technology in school, the US government aims to reduce inequalities in education that arise from the students' socioeconomic background. The intention is to improve the equality of opportunities by taking advantage of a more personalized learning experience with digital devices.

4. Data

This research uses data of the Trends in International Mathematics and Science Study (TIMSS), a project of the International Association for the Evaluation of Educational Achievement (IEA). TIMSS is a cross – national survey following trends in maths and science of fourth and eighth grade students. The test has been administrated every four years since 1995. Our empirical analysis uses the 2015 wave, which covers 56 different countries. Our focus lies on the eighth grade sample of the United States since we assume that eighth grade students are already more familiar with technology than fourth grade pupils which allows for a more effective computer use in school. TIMSS collects a wide range of variables in the context of education. The students, their teachers, and the principals of the schools are asked about their backgrounds, their attitudes, experience and practices in teaching and learning of maths and science. Furthermore, the essential point for our analysis is that TIMSS allows the link of the students to their teachers. Every student is observed twice, once in maths and once in science.[1] It is noteworthy that the classroom composition of students is allowed to vary between the subjects.

4.1 Sample selection

The full sample consists of 10,221 students in 534 maths and science classes in 246 schools all over the US. We exclude 3,032 students who have more than one maths or science teacher.[2] 7,189 students remain in the sample. As a robustness check, we will conduct our

[1] Science consists of biology, chemistry, earth science and physics.

[2] The large number of students who have more than one teacher might be due to the fact that science consists of more than one subject. Often students do not have the same teacher in these subjects.

analyses leaving these students in the sample and using the average computer use over the different teachers in one subject (section 6.2). We drop 2,094 observations, where teachers do not provide complete answers to the questions of interest. 5,095 students remain in the final sample. Table A.1 (see Appendix) presents descriptive statistics for our final sample and the whole sample for a selection of students' and classroom variables. Although we need to drop a large part of the whole sample, overall, we do not find significant differences in the students' characteristics. Hence, our sample is representative for all students that were tested in the US in 2015. Table 4.1 presents the students' characteristics by the assignment of digital tools in classrooms. We find strong significant differences for the categories: Internet use at home, parental education and the school characteristics. As expected, we find significant differences for the students' Internet use at home. Students' whose teachers use computers more frequently during the lecture, use the internet more often when studying at home. If teachers make frequent use of computers in classrooms, students are naturally more likely to do homework or communicate with the teacher digitally.

4.2 Outcome Variables

TIMSS tests the knowledge of eighth grade students in maths and science according to their curriculum. The overall test score measures the students' performance on a range from 0 being the lowest score to 1000 being the highest score attainable. For our analysis, we standardize the test scores to a 0 to 1 range to ensure comparability. TIMSS does not only provide the students' overall test score but also includes subscores within the subjects.[3] Furthermore, subscores are available for three different cognitive domains: knowing, applying and reasoning. While the first two measure the students' competence to reproduce knowledge, the reasoning score represents the students' capability to solve complex questions in new contexts. We further need to take into account the specific design of the TIMSS test scores. Every student only answers a subset of the total question pool. The IEA is then using the Item Response Theory (Hambleton & Swaminathan, 2013) to estimate five plausible values of test scores for each student. All our estimators will account for the additional uncertainty that arises through this methodology.

[3]Maths subscores are Algebra, Data and Chance, Geometry and Number. For science available subscores are biology, chemistry, earth science and physics.

We further use the students' motivation as outcome variable. For that purpose, we exploit the TIMSS students' questionnaire. Students are asked about their motivation separately, once for the maths and once for the science class. We use the following six variables: student enjoys class, student finds class boring, student likes the class, student refers to class as its favorite, student finds the teacher gives interesting things to do and student finds the class helpful for the future. We study the effect of each of the six variables separately. For this we assign the value 0 if students disagree a lot, 1/3 for disagreeing a little, 2/3 for agreeing a little and 1 for agreeing a lot.

To ensure comparability of our results we normalize our outcome variables to mean 0 and standard deviation 1 in the regression analyses.

4.3 Treatment Variable

We use information about the use of computers during the maths and science lecture from the teacher questionnaire. The teacher is asked about the frequency of the usage of computers during the lessons. Thereby the teacher is requested to use a four – point scale (never or almost never, once or twice a month, once or twice a week and every or almost every day) for describing how often digital tools are used. We assign the value 0 if computers are never used in class, 1 if computers are used once or twice a month, 2 for once or twice a week and 3 if the computer is used every or almost every day. Both the maths and the science teacher state the frequency of technology use for different in – class activities. In both subjects, the teacher is asked how often technology is used to practice skills & procedures, look up ideas & information and process & analyze data. Additionally, the maths teacher specifies the frequency of using computers to explore maths principles & concepts. The science teacher is asked about the usage of digital devices for scientific procedures and studying natural phenomena through simulations. We only consider the three activities that appear in both teacher questionnaires to gain reliable information about the between – subject variation of technology use. As a robustness check, we will use an alternative definition of the treatment variable to be able to account for all four activities in maths and all five activities in science (see section 6.2). Since all three activities cover the use of technology for individual learning of students, we weight them equally in our treatment variable. We assign values ranging between 0 and 1 in steps of

1/9 for the use of computers for the three different activities, depending on the frequency of the computer use during the lecture. We follow this procedure for both the maths and the science class. To ensure comparability of our results, we normalize use frequency of digital devices to mean 0 and standard deviation 1 in the regression analyses.

Figure A.2 shows the different frequency of using digital tools by the subject. In both subjects the frequency varies between 0 and 1 and we observe full support within this range. Nevertheless, in science classes students work on average more often with digital devices. Our subject fixed effect approach takes care of the different means for using digital devices in the two subjects (section 5). Further, figure A.1 presents the distribution of the variation between science and maths.[4] For our within – student between – subject fixed effects model, we need variation in the usage of digital devices between the subjects. In our sample, 55 percent of students have a different intensity of using digital tools in science and in maths classes.[5]

4.4 Control Variables

In our regression, we include different sets of teacher controls (see tables 4.2, A.2). All these variables are observed in the TIMSS teacher questionnaire. We include indicator variables for teachers' gender, their age range (under 30 years, between 40 and 49 years, at least 50 years), their major in science, maths or education, a teaching certificate and the existence of a postgraduate degree. Moreover, we add teaching experience (under 1 year and 1 to 5 years) and the teachers' motivation. We use the following variables to capture the teachers' motivation: the teacher has participated in professional development for the subjects' content, for pedagogy or improvement of instruction, the curriculum, for integrating information technology in the lecture, improving the students' critical thinking or problem solving skills, the subjects' assessment or addressing individual students' needs. Furthermore, we include the teachers' feelings, particularly: the teacher feels content about the profession as a teacher, is satisfied with being a teacher at this school, finds the work full of meaning and purpose, is enthusiastic, inspired, proud and wants to continue teaching as long as possible. Table A.2 shows teacher characteristics by subject. We

[4] To obtain the variation we subtract the use digital tools in maths from the use digital tools in science.

[5] This is slightly higher than the international average reported by Falck et al. (2018) in their study on digital learning. In their international sample, 45 percent of students are exposed to different frequencies of computer use in maths and science.

find small and mostly insignificant differences between science and maths teachers. As expected, strong and significant differences are found for the teachers' major in the specific subject. Additionally, the students have significantly more maths than science lectures.[6]

Furthermore, table 4.2 presents the teacher characteristics by the use of digital tools in classroom. 172 maths or science teachers use digital tools at least once or twice a month. 241 teachers do never use digital tools during their lecture. We find only small and often insignificant differences for the teachers' characteristics. Significant differences are found for teachers' motivation and feelings. Overall, to capture all these variations we include different sets of controls in our regression.

[6] Again, this might be due to the fact that science consists of different subjects.

Table 4.1: Descriptive statistics – student, class and school – by treatment.

	Digital tools				
	<Mean		>= Mean		
Variable	**Mean**	**SD**	**Mean**	**SD**	**Diff.**
Student					
Student is female	0.508	0.500	0.520	0.500	-0.012
Number books at home					
Number books at home: 11 – 25	0.216	0.411	0.191	0.393	0.025*
Number books at home: 26 – 100	0.295	0.456	0.293	0.455	0.002
Number books at home: 101 – 200	0.171	0.377	0.183	0.387	-0.012
Number books at home: > 200	0.154	0.361	0.165	0.371	-0.011
Number devices at home: 1 – 3	0.049	0.217	0.056	0.230	-0.007
Number devices at home: 4 – 6	0.199	0.399	0.220	0.415	-0.021
Number devices at home: 7 – 10	0.316	0.465	0.286	0.452	0.030*
Number devices at home: > 10	0.418	0.493	0.426	0.495	-0.008
Internet use at home					
Access textbook	0.479	0.500	0.604	0.489	-0.125***
Access assignments	0.558	0.497	0.746	0.435	-0.188***
Collaborate with	0.571	0.495	0.643	0.479	-0.072***
Communicate with teacher	0.361	0.480	0.458	0.498	-0.097***
Find info to aid in maths	0.606	0.489	0.645	0.479	-0.039**
Find info to aid in science	0.543	0.498	0.607	0.489	-0.064***
Parental education					
Mom lower secondary	0.062	0.242	0.048	0.213	0.014*
Mom upper secondary	0.209	0.407	0.199	0.400	0.010
Mom university	0.446	0.497	0.483	0.500	-0.037**
Dad lower secondary	0.063	0.244	0.046	0.211	0.017*
Dad upper secondary	0.220	0.414	0.223	0.417	-0.003
Dad university	0.359	0.480	0.384	0.487	-0.025
Nativity					
Never speaks English at home	0.007	0.083	0.010	0.098	-0.003
Sometimes speaks English at home	0.066	0.248	0.067	0.251	-0.001
Almost always speaks English at home	0.157	0.364	0.149	0.356	0.008
Immigrant	0.948	0.222	0.943	0.233	0.005
School					
Community, 3001 – 15,000 people	0.128	0.335	0.169	0.375	-0.041***
Community, 15,001 – 50,000 people	0.229	0.421	0.252	0.434	-0.023
Community, 50,001 – 100,000 people	0.276	0.447	0.100	0.300	0.176***
Community, 100,000 – 500,000 people	0.126	0.331	0.152	0.359	-0.026**
Community, more than 500,000 people	0.084	0.278	0.206	0.404	-0.123***
Parental involvement in school – very low	0.068	0.251	0.040	0.197	0.028***
Parental involvement in school – low	0.264	0.441	0.263	0.440	0.001
Parental involvement in school – medium	0.322	0.467	0.348	0.476	-0.026
Parental involvement in school – high	0.225	0.418	0.218	0.413	0.007
Number of observations	3,138	3,138	1,957	1,957	

Note: We calculate the overall mean of all students exposure to digital learning in school. We then group the students by below or above average exposure to digital learning and calculate differences in their characteristics. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4.2: Descriptive statistics – teachers by usage of digital tools.

	Digital tools				
	No Use		Use		
Variable	**Mean**	**SD**	**Mean**	**SD**	**Diff.**
Teacher is female	0.653	0.477	0.692	0.463	-0.039
Full teaching certificate	0.610	0.489	0.779	0.416	-0.169***
Major in science	0.427	0.496	0.529	0.501	-0.102*
Major in maths	0.552	0.498	0.640	0.482	-0.088
Major in education	0.357	0.480	0.448	0.499	-0.091
Teacher younger than 30	0.158	0.365	0.174	0.381	-0.016
Teacher aged 40 – 49	0.261	0.440	0.291	0.455	-0.03
Teacher older than 50	0.290	0.455	0.227	0.420	0.063
Teaching experience < 1 year	0.071	0.257	0.087	0.283	-0.016
Teaching experience 1 – 5 years	0.170	0.377	0.180	0.386	-0.010
Postgraduate Degree	0.593	0.492	0.581	0.495	0.012
Teacher motivation					
Subject content classes in last 2 years	0.726	0.447	0.773	0.420	-0.047
Subject pedagogy classes in last 2 years	0.668	0.472	0.692	0.463	-0.024
Subject curriculum classes in last 2 years	0.776	0.418	0.756	0.431	0.020
Subject related IT classes in last 2 years	0.568	0.496	0.721	0.450	-0.153**
Subject critical thinking classes in last 2 years	0.635	0.482	0.663	0.474	-0.028
Subject assessment classes in last 2 years	0.539	0.499	0.523	0.501	0.016
Subject student needs classes in last 2 years	0.589	0.493	0.640	0.482	-0.051
Teacher feelings					
Content profession	0.788	0.409	0.866	0.341	-0.078*
Satisfied	0.784	0.412	0.831	0.375	-0.047
Meaning and purpose	0.822	0.384	0.907	0.291	-0.085*
Enthusiastic	0.851	0.357	0.913	0.283	-0.062
Inspires	0.784	0.412	0.872	0.335	-0.088*
Proud	0.925	0.263	0.953	0.211	-0.028
Continue as a teacher	0.772	0.421	0.785	0.412	-0.013
Classroom					
Class size	27.73	10.510	26.170	11.530	1.560
Total teaching time per week (min/week)	248.909	75.627	255.127	84.622	-6.218
Tracking according to ability	0.556	0.498	0.466	0.500	0.090
Number of observations	241	241	172	172	

Note: " Use of digital tools " refers to those teachers who use digital tools at least once or twice a month. " No Use " refers to those who never use digital tools in classrooms. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

5. Empirical Framework

To estimate the causal effect of digital teaching practices on learning outcomes, one would ideally randomly assign computer use in classrooms to students. The effect of digital learning could then be estimated using the conventional education production function:

$$Y_{ijk} = \alpha_j + \beta_1 B_{ijk} + \beta_2 S_{ijk} + \beta_3 T_{ijk} + \beta_4 Digtool_{ijk} + \varepsilon_{ijk} \tag{5.1}$$

The test score Y_{ijk} of student i in subject j in school k is explained by the students' characteristics B_{ijk}, teacher – and classroom characteristics T_{ijk}, school characteristics S_{ijk}, subject characteristics α_j and the variable of interest $Digtool_{ijk}$. Y_{ijk} can further capture the subscores for distinctive cognitive skills and the motivation of the student i in subject j in school k. The error term ε_{ijk} includes all unobservable influences of students μ_i, teachers ξ_j, schools ζ_k and unobservables ψ_{ijk} on students' achievement:

$$\varepsilon_{ijk} = \mu_i + \xi_j + \zeta_k + \psi_{ijk} \tag{5.2}$$

In this empirical framework it is assumed that the usage of digital learning methods is uncorrelated with all unobservable student, teacher and school characteristics. This assumption is likely to be violated due to across – school and within – school selection of students according to their preferences and inherent ability. Students with high inherent ability are likely to self – select into schools and classes which make more use of information technology. In table 4.1, student and school characteristics are presented by treatment status. We indeed observe significant differences between students and schools that use computers in classrooms and those who do not use digital devices. A naive OLS estimator would thus be biased. We overcome this likely source of bias by using a student fixed effects approach that has been established in previous studies on teaching practices (Bietenbeck, 2014; Dee, 2005, 2007; Schwerdt & Wuppermann, 2011). We therefore exploit the quasi – panel structure of the TIMSS data. Since students are tested twice, once in maths, once in science, we can use the first difference to eliminate student, subject and school fixed effects:

$$\triangle Y_i = \alpha_s - \alpha_m + (\beta_{1s} - \beta_{1m}) B_i + (\beta_{2s} - \beta_{2m}) S_i + \beta_{3s} T_{is} - \beta_{3m} T_{im} + (\beta_{4s} - \beta_{4m}) Digtool_i + n_i \tag{5.3}$$

$$n_i = \xi_s - \xi_m + \psi_{is} - \psi_{im} \tag{5.4}$$

With $\triangle Y_i$ being the difference in the outcome variable between science and maths and $\alpha_s - \alpha_m$ accounting for subject fixed effects. n_i is the remaining error term that includes differences in teacher characteristics between the subjects $\xi_s - \xi_m$ and unobserved differences between the subjects $\psi_{is} - \psi_{im}$. We thus account for within – and across – school selection of students to digital teaching. Following this approach, we gain a causal estimator for the effect of digital teaching practices on students' learning outcomes. However, we still think of two possible ways the error term n_i could be correlated with our variable of interest $Digtool_{ijk}$.

First, students' inherent ability could differ substantially between subjects. This would cause our estimator to be biased since our model only accounts for across – subject fixed student characteristics. We argue that this possible source of bias is not of great concern in our study. Maths and science are similar subjects that require similar abilities and skills. In addition, Clotfelter et al. (2010) found that abilities between subjects are highly correlated which further diminishes concerns about this source of bias.

Second, teachers' unobservable characteristics could be correlated with their choice of using information technology in the classroom. For example, highly motivated teachers could be more likely to use digital learning methods. This would lead our estimator to be biased since the higher motivation of the teacher could affect the students' test score or motivation in other ways than through the use of digital tools. Table 4.2 presents teacher characteristics by the use of digital devices. Overall, we do not observe many significant differences between the teachers who use and do not use computers in our sample. However, there is some evidence for significant differences regarding their feelings and motivation. Teachers who use digital tools tend to be happier with their job and more motivated. One possible way to overcome this problem and account for these differences would be to use teacher fixed effects. However, we cannot use teacher fixed effects in our approach since we exploit the between – teacher within – student variation of the use of digital tools. Our identification strategy relies on the variation in the use of computers between the maths and the science teacher.[1] We can thus not make use of teacher fixed

[1]If students have the same teacher in maths and science our model will account for the within – teacher

effects but instead address this problem by controlling for a powerful set of teacher and classroom characteristics (see tables 4.2, A.2). In particular, we make use of the wide range of questions addressing the teachers' motivation and feelings to control for inherent ability and motivation.

6. Results

Tables 6.1, 6.2 and A.3 present estimates of the model used in section 5 for the US. All tables use a within – student between – subject fixed effects approach and exploit the variation of teachers between the subjects maths and science. Our variable of interest " Digital tools " covers the use of digital devices during the classes by the teacher (see section 4). In this section, we analyze the effects of using digital tools in the classroom on students' overall achievement, their cognitive skills and their motivation.[1]

Table 6.1 shows the effects of digital tools on the overall students' achievement by including different sets of controls. In column (1), no controls are included. Column (2) includes teacher characteristics such as gender, age, certificates, experience, motivation and feelings of the teacher which are presented in table A.2. The model in column (3) includes both teachers and several classroom controls such as class size, teaching time per week and tracking according to ability (see table A.2). Moreover, column (4) excludes teachers' motivation and the teachers' feelings as controls. The model in column (5) only includes classroom controls.

The effect on overall student test scores is positive, however small and insignificant.[2] A one – standard – deviation increase in the frequency of using digital tools in the classroom increases students' overall achievement by 1.2 – 3.6 percent of a standard deviation (depending on the included controls). In other words, going from no or almost no computer use at all to a every or almost every day computer use increases the students' overall achievement by 2.76 – 8.28 percent of a standard deviation. These effect sizes are small to

variation of the use of digital tools. Though, only 170 students in our sample of 5,095 students have the same teacher in maths and in science.

[1] Our outcome variables and the frequency of using digital devices is normalized to mean 0 and standard deviation 1 in the regression analyses.

[2] By including only teacher controls (column (2)) we find a statistically significant effect at the 10 percent level.

modest, compared for example with estimators of 10 – 15 percent of a standard deviation in the measurement of teacher value added (Hanushek & Rivkin, 2010) and on average 25 – 30 percent of a standard deviation learning outcome of a student in one school year (Woessmann, 2016). Nevertheless, it is again important to point out that the overall achievement is not significantly associated with the use of digital tools in the classroom.

Furthermore, this finding does not vary a lot over the distinctive cognitive skills of the students. We find positive, but small and mostly insignificant effects on all three categories of cognitive skills namely knowing, applying and reasoning (table A.3). A one – standard – deviation increase in the frequency of using digital tools in the classroom increases students' cognitive skills by 1.1 – 4.2 percent of a standard deviation (depending on the included controls). Put differently, a rise from using no or almost no digital devices to a daily use increases cognitive skills by 2.64 – 10.08 percent of a standard deviation. Further, for all three cognitive skills, we find a significant association between our outcome variable and computer use by only including teacher controls. This significant effect ranges from 3.3 – 4.2 percent of a standard deviation.

We do not differentiate between different uses of computers. The treatment variable is defined as the combined computer use to practice skills & procedures, look up ideas & information and process & analyze data. Specific computer activities on its own could have positive or negative effects which results in an overall small respectively ”null effect” (Falck et al., 2018). This ” null effect ” could explain our small and mostly insignificant effects.

Table 6.2 presents the effects of digital tools on the six different students' motivation variables particularly: student enjoys class, student finds class boring, student likes the class, student refers to class as its favorite, student finds the teacher gives interesting things to do and student finds the class helpful for the future. Again, we include different sets of controls in our regression. Compared to our previous results, estimates are larger in their absolute values and are almost always statistically significant.

Notably, favorite subject shows the strongest effect. Irrespective of whether teacher and classroom controls are included the positive effect is highly significant. A one – standard – deviation increase in the frequency of using digital tools in classrooms increases students' motivation of favorite subject by 5.6 – 6.9 percent of a standard deviation (depending on the included controls). In other words, an increase of no or almost no digital tools use at all to a daily use increases the reference of the students' favorite subject by 10.64 – 13.11 percent of a standard deviation.

Additionally, table 6.2 shows a strong effect for liking the subject. This effect ranges between 4.6 – 5.3 percent of a standard deviation. Similar positive effects are observed for enjoy, the teacher gives interesting things to do and the student thinks that the subject will help them in the future.

By contrast, we find statistically negative significant effects for the student finds the subject boring. The effect sizes suggest that a one – standard - deviation increase in the frequency of using digital tools in classrooms decreases that the student find the subject boring by 3.5 – 5.6 percent. Expressed differently, going from no or almost no use of digital tools to an everyday use, lowers it by 6.30 – 10.08 percent of a standard deviation. This finding is in line with the results we found for the other motivation variables.

While we cannot find evidence for strong effects on overall and cognitive test scores, students' motivation increases by integrating digital tools in the classroom. One explanation could be that although a student might enjoy and is interested in the subject, this does not necessarily go hand in hand with putting more effort into studying and seeing the importance of hard work. Thus, positive attitudes do not necessarily predict higher achievement (Brusic, 1991).

Overall, we find evidence that the use of computers in the classroom raises students' motivation. When teachers use technology students enjoy studying more, find the classes less boring and like the subject more or even tend to state it as their favorite subject. While we cannot find evidence for a strong effect of technology use on test scores, these findings on increased motivation could affect students' long run education prospects.

Table 6.1: Digital tools and students' overall achievement in the US.

	(1)	(2)	(3)	(4)	(5)
Digital tools	0.016 (0.015)	0.036 (0.018)	0.023 (0.020)	0.021 (0.016)	0.012 (0.017)
Teacher controls		Y	Y	Some	
Class controls			Y		Y
Number of students	5,095	5,095	5,095	5,095	5,095

Note: Dependent variables in all columns are the within – students between – subjects differences in standardized test scores. Different sets of controls are included (see A.2). In column (4) we exclude teacher motivation and the teacher feelings as controls. Column (5) only includes the classroom controls. Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6.2: Digital tools and students' motivation in the US

	(1)	(2)	(3)
Enjoy			
Digital tools	0.036*	0.027	0.040*
	(0.014)	(0.016)	(0.019)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,976	4,976	4,976
Boring			
Digital tools	-0.035*	-0.035*	-0.056**
	(0.014)	(0.016)	(0.019)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,862	4,862	4,862
Like			
Digital tools	0.046**	0.038*	0.053**
	(0.014)	(0.016)	(0.019)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,869	4,869	4,869
Favorite subject			
Digital tools	0.056***	0.061***	0.069***
	(0.014)	(0.016)	(0.019)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,962	4,962	4,962
Interesting things to do			
Digital tools	0.033*	0.022	0.050**
	(0.014)	(0.016)	(0.018)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,954	4,954	4,954
Subject will help me			
Digital tools	0.034*	0.030	0.051**
	(0.014)	(0.016)	(0.019)
Teacher controls		Y	Y
Class controls			Y
Number of students	4,948	4,948	4,948

Note: We exclude all observations with missing information about students' motivation. Dependent variables in all columns are the within − students between − subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance.Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

6.1 Heterogeneity

In this section, we test for possible heterogeneity across different subgroups of students. Doing this, we examine the effects of digital tools on students' overall test achievement, their cognitive skills and their motivation by gender, socioeconomic background and the number of digital information devices available at home. Therefore, we divide our sample in two subsamples for each of the three dimensions. Given the widening education gap between boys and girls with boys falling behind (DiPrete & Buchmann, 2013), it is important to study the effect of digital learning in this context. Further, heterogeneous effects by socioeconomic background need to be studied in order to evaluate the impact of digital learning on equality in education. In this section, we make a contribution to the existing literature by applying the fixed effects approach and focus on the impact on students' motivation by our heterogeneous subgroups.

First, we answer the question if the use of computers during the lecture has different impacts on female and male students. Our sample consists of 2,599 female and 2,468 male students. 28 students have not stated their sex. The results in table A.4 and table A.8 show no substantial differences for the effect of digital tools on female and male students' test scores. Moreover, the effects of digital tools are not significant neither for females' or males' overall test score achievement or the gender specific cognitive skills (see table A.8, Panel "female" and "male").[3]

Further, the gender specific effect of digital tools on the students' motivation does not differ significantly (see table 6.3). Nevertheless, we almost always obtain larger positive and mostly significant effects for males. As for the whole sample we find strong and highly significant effects for favorite subject. A one – standard – deviation increase in the frequency of using digital tools in class increases males' motivation of favorite subject by 5.6 – 8.3 percent of a standard deviation (depending on the included controls, table A.9). Also, the effect for boring is much more negative for male than for female students. Noteworthy, for male we observe mostly significant effects. One possible explanation for this pattern could be that males are more familiar with the use of computers. Often males spent more time playing digital games than females, whereas females associate digital tools primarily with communication and educational assistance (Weiser, 2000). Nevertheless,

[3]As one exception we find a small significant effect in one specification of the knowing score for male students (column (2)).

we do not find evidence for significant differences between female and male students.

Next, we study the effect of digital devices on students with different education levels of their parents. Previous studies have shown that the educational level of parents has a strong and significant effect on students' achievement and their educational aspiration (Davis-Kean, 2005; Fiorini, 2010; Pagani et al., 2016; Sewell & Shah, 1968). High educated parents are captured as those who have a post — secondary or an even higher degree as a highest education level. The highest education level for low educated parents is an upper secondary degree.

We find different results for the students' overall achievement and their cognitive skills regarding to the parental education level (see tables A.5, A.8). However, these findings are not statistically significant. The effects of digital tools on the students with a low educated background are stronger than for students with high educated parental background.[4] However, the results presented in table A.5 and table A.8 are never statistically significant for low and high SES backgrounds.[5]

Additionally, depending on the parental educational background we find statistically significant differences for the students' motivation (table 6.3). We observe larger and significant effects for almost all motivation variables for students with a lower educated parental background. Especially strong is the effect on favorite subject (see table A.10 columns (4) – (6)). A one – standard – deviation increase in the frequency of using digital tools in the classroom increases the motivation of favorite subject of students with a low socioeconomic background by 10.50 – 13.50 percent of a standard deviation (depending on the included controls). We also find substantial effects for enjoying and liking the subject. Once again, the effect on students' boredom with low educated parents is strongly negative and highly significant. The effects for students with high educated parents are small and not statistically significant (see table A.10). Additionally, as a robustness check, we use the number of books at home to capture the students' socioeconomic background (Falck et al., 2018).[6] We find evidence for a stronger effects for few books at home (see tables A.6, A.8 and A.11). Again, the differences between many and only a few books at home are statistically significant (see table A.11).

[4]The effects are even stronger compared to section 6.

[5]As one exception we find a small significant effect in one specification of the knowing score for low SES students (column (2)).

[6]Students with few books at home have not more than 25 books. Students with many books have more than 25 books at home.

One possible explanation for these differences could be that students from low SES families have less access to digital devices at home and thus feel more motivated when they get the chance to use technology in school. We therefore also look at the effects of using digital tools by the number of digital information devices available at home. Students with many digital devices have more than 10 devices in the household.[7] Computers, tablets, smartphones, smart TVs, and e-readers are defined as digital information devices. Contrarily to our hypothesis, we almost always observe stronger effects for students with many devices (see tables A.7, A.8 and A.12). Nevertheless, we do not find statistically significant differences among this dimension. We further find that there is no strong correlation (r=0.17) between the students' socioeconomic background [8] and the number of digital information devices at home.[9] This means that there are no systematic differences in the number of digital devices at home between low SES and high SES families. The heterogeneous effects by socioeconomic background can thus not be explained by the number of devices available at home.

We argue that the differences by family background can rather be explained by the kind of use of computers and tablets at home and attitudes towards technology in the different groups. Livingstone et al. (2015) find that parents in low SES families are less confident with technology and thus tend to be more restrictive about the technology use of their children. Digital devices are implemented in the overall reward − and − punishment system at home. Less educated parents are also less likely to consider computers as educational tools, whereas their children are more likely to choose technology for new learning purposes than their counterparts from high SES families (Linebarger & Chernin, 2003). The combination of this positive attitude towards technology use for education and the restricted usage at home could explain why the motivation of these children increases when computers are used in the classroom.

Overall, when looking at the different effects of digital tools in the classroom on students' motivation, significant differences are not observed between genders and by the number of devices at home but along parental education level dimensions.

[7] As a robustness check we also study a different classification: students with many devices are those who have more than six digital information devices at home. We find similar effects.

[8] We consider both: parental education and number of books at home.

[9] The correlation coefficient between the number of digital information devices at home and the number of books at home is r = 0.170. The correlation between number of devices at home and parental education is r= 0.106.

Table 6.3: Digital tools and students' motivation – Heterogeneity.

	Gender			SES			Devices		
	Female (1)	Male (2)	Diff. (3)	High (4)	Low (5)	Diff. (6)	Many (7)	Few (8)	Diff. (9)
Enjoy									
Digital tools	0.019	0.036	-0.017	-0.007	0.101**	-0.108	0.035	0.026	0.009
	(0.023)	(0.022)		(0.021)	(0.034)		(0.019)	(0.028)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,565	2,411		2,709	1,308		2,105	2,849	
Boring									
Digital tools	-0.023	-0.046*	0.023	0.002	-0.103**	0.105**	-0.057*	-0.02	-0.037
	(0.023)	(0.023)		(0.021)	(0.033)		(0.019)	(0.028)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,513	2,349		2,654	1,268		2,062	2,779	
Like									
Digital tools	0.028	0.046*	-0.018	-0.013	0.107**	-0.12***	0.055*	0.024	0.031
	(0.023)	(0.022)		(0.021)	(0.035)		(0.019)	(0.028)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,510	2,359		2,649	1,284		2,061	2,786	
Favorite Subject									
Digital tools	0.050*	0.074***	-0.024	0.018	0.135***	-0.117***	0.076**	0.051*	0.025
	(0.023)	(0.021)		(0.021)	(0.033)		(0.019)	(0.027)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,564	2,398		2,705	1,303		2,103	2,837	
Interesting things to do									
Digital tools	0.020	0.027	-0.007	0.006	0.052	-0.046	0.031	0.017	0.014
	(0.022)	(0.022)		(0.021)	(0.032)		(0.019)	(0.026)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,557	2,397		2,705	1,299		2,102	2,830	
Subject will help me									
Digital tools	0.019	0.042	-0.023	0.021	0.069*	-0.048	0.012	0.045*	-0.033
	(0.022)	(0.023)		(0.021)	(0.034)		(0.019)	(0.028)	
Teacher controls	Y	Y		Y	Y		Y	Y	
Number of observations	2,565	2,383		2,699	1,298		2,096	2,830	

Note: SES stands for the parental education level. We exclude all observations with missing information about students' motivation. Dependent variables in all columns are the within – students between – subjects differences in students' motivation. In tables A.9, A.10 and A.12 we additionally include different sets of controls. Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

6.2 Robustness

To check for robustness of our findings presented in section 6, we use an alternative measure for the frequency of the usage of digital tools by the teacher. The indices for the use of computers during maths and science lectures are not the only way in which the use of digital tools during the lecture can be measured. Various methods exist to determine how the treatment variable can be defined. So far, we only considered the three computer use activities that are alike for both subjects. We now define the treatment variable using the average frequency of computer use over all four activities in maths classes and five activities in science classes, respectively. Again, we use in both subjects the following questions: the teacher is asked how often technology is used to practice skills & procedures, look up ideas & information and process & analyze data. Additionally, the maths teacher specifies the frequency of using computers to explore maths principles & concepts. The science teacher is asked about the usage of digital devices to do scientific procedures and to study natural phenomena through simulations. Thereby, we again assign weights ranging between 0 and 3, for describing how often digital tools are used. Then, we compute the average of the weights over the four or five activity – questions among all teachers. Once again, we use a within – student between – subject fixed effects approach (see section 5).

We continue our analysis with the alternative definition of our treatment variable and run again the different regressions. Table A.13 (columns (1) – (3)) presents the estimates from the corresponding regressions for the overall academic test scores by including different sets of controls. Furthermore, in table A.14, results are reported for the students' cognitive skills: knowing, applying and reasoning. Table A.15 (columns (1) – (3)) presents the estimates in which the dependent variables are the different motivation variables of the students namely student enjoys class, student finds class boring, student likes the class, student refers to class as its favorite, student finds the teacher gives interesting things to do and student finds the class helpful for the future. By changing the way our treatment variable is defined we obtain overall slightly smaller results. Again, we merely observe weak to non significant results of the use of digital tools on students' overall achievement and their cognitive skills (see tables A.13 and A.14, columns (1) – (3)). Moreover, by including only teacher controls our effect of computer use in classrooms is statistically significant. Further, we find positive and mostly significant results for the students' motivation (table A.15, columns (1) – (3)).[10] Once more, we find the strongest effects of using digital tools for students identifying maths or science as its favorite subject. Additionally, an increase of using computers lowers the fact that the student finds the subject boring. Compared to table 6.2, the effects for boredom are smaller, but still significant.

Furthermore, as already mentioned in section 4, we do an additional robustness check by considering students with more than one teacher in maths or science as well. We now only exclude students who have not answered our question of interest. 7,691 students remain in the sample. For students with more than one teacher in a subject, we use the average frequency of using digital devices across the different teachers. We follow the same procedure to define our treatment variable as in section 4. Again, we use a fixed effect approach as our empirical model and include different sets of controls (see sections 4 and 5). Estimates presented in tables A.13, A.14 and A.15 are similar to our findings in section 6. Again, the effects on students' overall achievement and their cognitive skills are small and not significant. Our effects on students' motivation range in the same size as presented in table 6.2.

Doing an additional robustness check, we exclude classes which are unusually small or large. Classes with less than five or more than 50 students are not included in the following analysis. This is reasonable, since in these classes the student – teacher – ratio seems to be not representative. Finally, 4,378 students remain in the sample. Tables A.13, A.14 and A.15 (columns (4) – (6)) present estimates from the corresponding regressions. The findings are similar compared to the results obtained in section 6. The effects presented in tables A.13, A.14 and A.15 (columns (4) – (6)) are generally slightly smaller compared to the effects in section 6. The less significant results might be explained by our smaller sample.

Our overall results of the analysis are approved to be robust.

7. Discussion

The aim of this research is to analyze the effect of integrating digital tools in classrooms. While we cannot find evidence that the increased motivation through digital devices can

[10]For the student finds the subject boring we find statistically significant negative effects.

be translated into higher test achievements, motivation has an important influence. In this section the relevance and importance of our findings are discussed.

The TIMSS data used for our analysis is focused on testing curriculum knowledge. Thus, the development of soft – and non – cognitive skills like creativity, critical thinking, adaptability or team work is not sufficiently captured in the final test scores. One reason why we cannot find a strong effect on students' overall test scores could be that the use of technology is more effective to develop these non – cognitive abilities which are not tested in TIMSS (Mullis & Martin, 2013). Moreover, technology use could be viewed as a tool to strengthen abilities beyond the standard academic skills (Autor et al., 2003; Falck et al., 2018). Positive effects of digital game based learning on skills like problem solving are confirmed by Yang (2012). Furthermore, soft skills might be specifically important for long run effects like educational prospects, career opportunities and future earnings. These not through TIMSS captured skills are highly valued in the job market and have a growing relevance in our digitized world (Duncan & Dunifon, 2012; Heckman & Kautz, 2012). In addition, the use of computers in classrooms is likely to promote the general digital competence of students which has also been proven to increase career prospects (Lissitsa et al., 2017). Thus, digital learning in school could increase the returns to education without affecting scores in standardized tests.

Our results show that the usage of technology in classroom has the potential to increase students' motivation, as stated in the goals of the NETP (Thomas, 2016). It is also widely approved that highly motivated students perform significantly better than low motivated students (Amrai et al., 2011; Murayama et al., 2013; Tella, 2007). Further, more interested students are listening in a different way to the teacher and might be less distracted by their classroom – environment (Adler & Benbunan-Fich, 2013; Gupta & Irwin, 2016). However, it takes time to translate higher motivation to improvements in academic achievement (Bruinsma, 2004; Kuyper et al., 2000). The increased motivation due to the use of digital devices thus has the potential to improve test scores in the following years, which we could not test in our study. In addition, there are positive long run outcomes of enhanced motivation in school that cannot be captured through standardized tests. First, motivated students are less likely to drop out from school earlier (Alivernini & Lucidi, 2011). Second, students with a positive attitude towards maths or science are more likely to continue their studies in these subjects and start working in this field (Shaughnessy & Haladyna, 1985).

Our findings suggest that male students are more likely to enjoy maths and science classes with integrated digital tools. This might be rooted in former education the students have obtained from their parents or the elementary school. Research has shown that parents stick to gender – specific stereotypes (Jacobs et al., 1998; Lily, 1994; Parsons et al., 1982; Tenenbaum & Leaper, 2003) and communicate different expectations to sons and daughters (Vekiri & Chronaki, 2008). This promotes persistent differences between the genders in technology – related interests and skills which could explain our heterogeneous findings for males and females. Yet, we point out again that the differences between the genders have not proven to be significant.

We have also investigated heterogeneous effects by students' socioeconomic background. Our findings show that students from disadvantaged backgrounds gain more motivation from the implementation of technology in classrooms than their counterparts from a higher SES. This finding cannot be explained by differences in the number of devices available at home but instead by differing attitudes and types of usage at home (Livingstone et al., 2015). Digital tools in the classroom thus have the potential to improve equality of opportunities in education which is stated as one of the main goals of education policy (Thomas, 2016). This will lead to better opportunities in the labor market for low SES students and thereby contribute to overall economic growth (Barro, 2001; Hanushek & Woessmann, 2010).

Even though we used a wide range of variables to capture students attitudes, we are aware that motivation is complex and difficult to measure, which limits our study. Further, to capture the computer use in the classroom we do not differentiate between the different activities.[1] Specific computer activities on its own could have positive or negative effects which results in an overall small or even "null effect" (Falck et al., 2018). We are further aware that our study is limited since it only considers the TIMSS 2015 wave for the US. We only have a relatively small sample, which again limits our study. For further research it is advisable to check for external validity by examining different countries, times, age groups and subjects.

[1]The computer is used to practice skills & procedures, look up ideas & information and process & analyze data.

8. Conclusion

With this research we provide evidence that including digital tools in classrooms affects students' motivation positively. Our findings indicate that this type of teaching provides better conditions for learning maths and science, especially by stimulating students to develop positive attitudes towards these subjects. Furthermore, we find heterogeneous effects for students with different socioeconomic background. Students from disadvantaged backgrounds gain more from the implementation of digital devices in classrooms. We discussed the effect of higher motivation on non – curriculum knowledge and emphasized the relevance of students' abilities and attitudes for different areas of their life.

Based on our results, we recommend to expand the use of digital tools in classrooms. Even though there are no significant effects on achievement in the short run, the potential of technology to increase motivation is likely to have valuable long run effects. We discussed the improvement of soft and digital skills through the use of digital tools, which are highly valued in the job market. Nevertheless, the way how computers are integrated in classrooms must be improved. Access to technology is not enough, teachers should attend seminars and further educations to know how to use digital tools effectively. To integrate technology in classrooms teachers need the knowledge, resources, skills and support. They have the chance to strengthen positive attitudes and to change the negative attitudes towards maths and science by their way of structuring their lectures. The presented research leads towards many new questions. Similar studies for different subjects and age groups should be conducted. External validity should further be tested in an international context. Given our findings on enhanced motivation, long term effects of digital learning such as further education, career choices and earnings should be analyzed.

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A. Appendix

Table A.1: Descriptive statistics – student, class and school.

	Subsample		Whole sample		
Variable	**Mean**	**SD**	**Mean**	**SD**	**Diff.**
Student					
Student is female	0.513	0.500	0.501	0.500	0.012
Number books at home					
Number books at home: 11 – 25	0.206	0.405	0.218	0.413	-0.012
Number books at home: 26 – 100	0.295	0.456	0.292	0.455	0.003
Number books at home: 101 – 200	0.176	0.381	0.161	0.368	0.015
Number books at home: > 200	0.158	0.365	0.145	0.352	0.013
Number devices at home: 1 – 3	0.052	0.222	0.054	0.226	-0.002
Number devices at home: 4 – 6	0.207	0.405	0.211	0.408	-0.004
Number devices at home: 7 – 10	0.304	0.460	0.308	0.462	-0.004
Number devices at home: > 10	0.421	0.494	0.412	0.492	0.009
Internet use at home					
Access textbook	0.527	0.499	0.513	0.500	0.014
Access assignments	0.630	0.483	0.632	0.482	-0.002
Collaborate with	0.599	0.490	0.597	0.490	0.002
Communicate with teacher	0.398	0.490	0.386	0.487	0.012
Find info to aid in maths	0.621	0.485	0.626	0.484	-0.005
Find info to aid in science	0.568	0.495	0.566	0.496	0.002
Parental education					
Mom lower secondary	0.057	0.231	0.062	0.242	-0.005
Mom upper secondary	0.205	0.404	0.205	0.404	0.000
Mom university	0.460	0.498	0.440	0.496	0.020
Dad lower secondary	0.057	0.232	0.069	0.253	-0.012 *
Dad upper secondary	0.221	0.415	0.219	0.414	0.002
Dad university	0.369	0.483	0.351	0.477	0.018 *
Nativity					
Never speaks English at home	0.008	0.089	0.011	0.105	-0.003
Sometimes speaks English at home	0.067	0.249	0.085	0.280	-0.018 *
Almost always speaks English at home	0.154	0.361	0.172	0.377	-0.018
Immigrant	0.946	0.226	0.942	0.234	0.004
Number of observations	5.095	5.095	10.221	10.221	

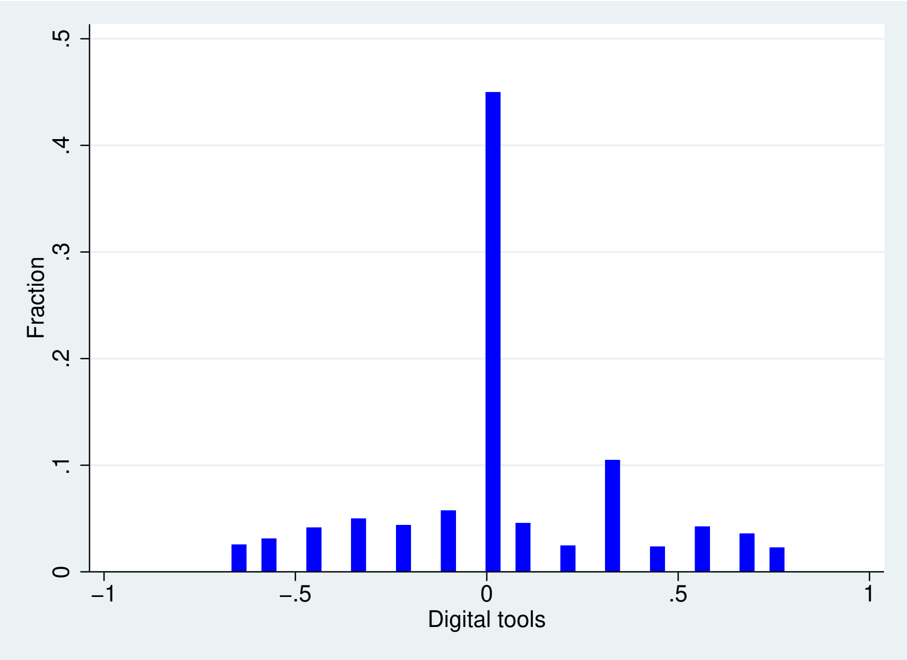
Note: Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.2: Descriptive statistics – teacher by subject.

	Science		Maths		
Variable	**Mean**	**SD**	**Mean**	**SD**	**Diff.**
Teacher is female	0.645	0.480	0.692	0.463	-0.047
Full teaching certificate	0.676	0.469	0.684	0.466	-0.008
Major in science	0.794	0.405	0.153	0.361	0.641***
Major in maths	0.525	0.501	0.651	0.478	-0.126**
Major in education	0.407	0.492	0.383	0.487	0.024
Teacher younger than 30	0.157	0.365	0.172	0.379	-0.015
Teacher aged 40 – 49	0.260	0.440	0.287	0.453	-0.027
Teacher older than 50	0.270	0.445	0.258	0.439	0.012
Teaching experience < 1 year	0.093	0.291	0.062	0.242	0.031
Teaching experience 1 – 5 years	0.167	0.374	0.182	0.387	-0.015
Postgraduate Degree	0.583	0.494	0.593	0.492	-0.010
Teacher motivation					
Subject content classes in last 2 years	0.716	0.452	0.775	0.419	-0.059
Subject pedagogy classes in last 2 years	0.647	0.479	0.708	0.456	-0.061
Subject curriculum classes in last 2 years	0.740	0.440	0.794	0.405	-0.054
Subject related IT classes in last 2 years	0.608	0.489	0.656	0.476	-0.048
Subject critical thinking classes in last 2 years	0.672	0.471	0.622	0.486	0.050
Subject assessment classes in last 2 years	0.475	0.501	0.589	0.493	-0.114*
Subject student needs classes in last 2 years	0.667	0.473	0.555	0.498	0.112*
Teacher feelings					
Content profession	0.819	0.386	0.823	0.383	-0.004
Satisfied	0.784	0.412	0.823	0.383	-0.039
Meaning and purpose	0.848	0.360	0.866	0.341	-0.018
Enthusiastic	0.897	0.305	0.856	0.351	0.041
Inspires	0.814	0.390	0.828	0.379	-0.014
Proud	0.926	0.262	0.947	0.224	-0.021
Continue as a teacher	0.804	0.398	0.751	0.433	0.053
Classroom					
Class size	28.536	10.981	25.701	10.781	2.835**
Total teaching time per week (min/week)	236.383	67.421	264.594	86.606	-28.211***
Tracking according to ability	0.282	0.451	0.750	0.434	-0.468***
Number of observations	204	204	209	209	

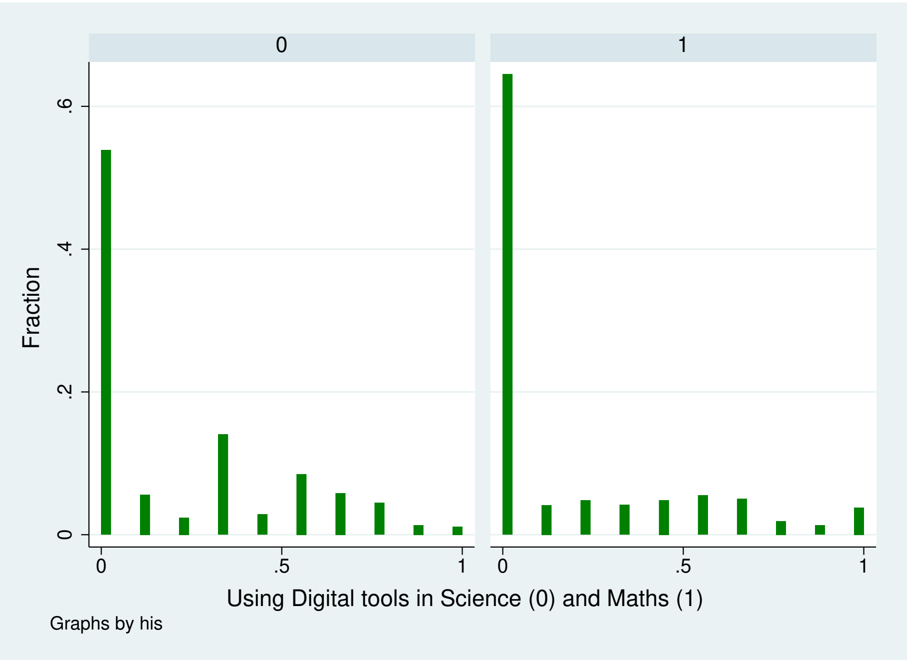
Note: Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure A.1: Histogram – Variation of using Digital tools.



Note: Shows the variation of using digital tools between science and maths. To obtain the variation we subtract the use digital tools in maths from the use digital tools in science. In our sample 55 percent of students have a different intensity of using digital tools in science and in maths classes.

Figure A.2: Histogram – Digital tools by subject.



Note: The histograms present the distribution of using digital tools in science and in maths. The histogram on the left hand side represents the use of digital devices in science, whereas the histogram on the right hand side represents the distribution in maths.

Table A.3: Digital tools and students' cognitive skills – USA.

	Knowing			Applying			Reasoning		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digital tools	0.025	0.042**	0.027	0.011	0.033*	0.016	0.020	0.036*	0.020
	(0.015)	(0.016)	(0.019)	(0.015)	(0.017)	(0.020)	(0.016)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	5,095	5,095	5,095	5,095	5,095	5,095	5,095	5,095	5,095

Note: Dependent variables in all columns are the within – students between – subjects differences in students' cognitive skills. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.4: Digital tools and students' overall achievement by gender.

	Female			Male		
	(1)	(2)	(3)	(4)	(5)	(6)
Digital tools	0.018	0.033	0.019	0.015	0.040	0.027
	(0.024)	(0.027)	(0.029)	(0.025)	(0.029)	(0.032)
Teacher controls		Y	Y		Y	Y
Class controls			Y			Y
Number of observations	2,599	2,599	2,599	2,468	2,468	2,468

Note: We exclude all observations with missing information about students' sex. 5,067 students remain in our sample. Dependent variables in all columns are the within – students between – subjects differences in standardized test scores. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.5: Digital tools and students' overall achievement by parental education.

	High educated			Low educated		
	(1)	(2)	(3)	(4)	(5)	(6)
Digital tools	0.006	0.027	-0.000	0.026	0.060	0.050
	(0.023)	(0.027)	(0.030)	(0.035)	(0.038)	(0.047)
Teacher controls		Y	Y		Y	Y
Class controls			Y			Y
Number of observations	2,748	2,748	2,748	1,371	1,371	1,371

Note: We exclude all observations with missing information about parents' highest education level. 4,119 students remain in our sample. Dependent variables in all columns are the within − students between subjects − differences in standardized test scores. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.6: Digital tools and students' overall achievement by number of books at home.

	Many books			Few books		
	(1)	(2)	(3)	(4)	(5)	(6)
Digital tools	0.004	0.027	-0.002	0.041	0.050	0.046
	(0.019)	(0.022)	(0.026)	(0.026)	(0.029)	(0.034)
Teacher controls		Y	Y		Y	Y
Class controls			Y			Y
Number of observations	3,259	3,259	3,259	1,836	1,836	1,836

Note: Dependent variables in all columns are the within − students between − subjects differences in standardized test scores. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.7: Digital tools and students' overall achievement by number of digital devices at home.

	Many Devices			**Few Devices**		
	(1)	(2)	(3)	(4)	(5)	(6)
Digital tools	0.027	0.042	0.022	0.006	0.026	0.018
	(0.023)	(0.027)	(0.030)	(0.022)	(0.025)	(0.029)
Teacher controls		Y	Y		Y	Y
Class controls			Y			Y
Number of observations	2,146	2,146	2,146	2,892	2,892	2,892

Note: We exclude all observations with missing information about number of devices at home. 5,038 students remain in our sample. Students with " Many Devices " at home have more than ten digital information devices. Dependent variables in all columns are the within − students between − subjects differences in standardized test scores. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.8: Digital tools and students' cognitive skills – Heterogeneity.

	Knowing			Applying			Reasoning		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Female									
Digital tools	0.023	0.037	0.017	0.004	0.023	-0.001	0.016	0.026	0.007
	(0.021)	(0.024)	(0.028)	(0.020)	(0.023)	(0.027)	(0.021)	(0.023)	(0.029)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	2,599	2,599	2,599	2,599	2,599	2,599	2,599	2,599	2,599
Male									
Digital tools	0.028	0.051^{*}	0.038	0.016	0.042	0.028	0.020	0.041	0.022
	(0.022)	(0.026)	(0.029)	(0.023)	(0.027)	(0.030)	(0.024)	(0.028)	(0.032)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	2,468	2,468	2,468	2,468	2,468	2,468	2,468	2,468	2,468
High educated									
Digital tools	0.007	0.033	0.005	0.006	0.030	0.000	0.011	0.030	0.005
	(0.021)	(0.023)	(0.028)	(0.021)	(0.023)	(0.027)	(0.022)	(0.024)	(0.029)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	2,748	2,748	2,748	2,748	2,748	2,748	2,748	2,748	2,748
Low educated									
Digital tools	0.059	0.077^{*}	0.052	0.029	0.063	0.045	0.044	0.071	0.044
	(0.034)	(0.038)	(0.043)	(0.040)	(0.043)	(0.050)	(0.038)	(0.042)	(0.048)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	1,371	1,371	1,371	1,371	1,371	1,371	1,371	1,371	1,371
Many books									
Digital tools	0.009	0.033	0.012	0.003	0.026	-0.001	0.005	0.022	-0.001
	(0.019)	(0.021)	(0.026)	(0.020)	(0.023)	(0.027)	(0.019)	(0.022)	(0.028)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	3,529	3,529	3,529	3,529	3,529	3,529	3,529	3,529	3,529
Few books									
Digital tools	0.050	0.058	0.039	0.033	0.051	0.038	0.051	0.063^{*}	0.040
	(0.029)	(0.032)	(0.041)	(0.028)	(0.031)	(0.042)	(0.028)	(0.031)	(0.041)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	1,836	1,836	1,836	1,836	1,836	1,836	1,836	1,836	1,836
Many Devices									
Digital tools	0.027	0.046	0.028	0.018	0.039	0.016	0.025	0.037	0.016
	(0.024)	(0.028)	(0.032)	(0.022)	(0.027)	(0.029)	(0.024)	(0.029)	(0.031)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	2,146	2,146	2,146	2,146	2,146	2,146	2,146	2,146	2,146
Few Devices									
Digital tools	0.021	0.035	0.021	0.002	0.025	0.009	0.012	0.028	0.013
	(0.022)	(0.024)	(0.028)	(0.020)	(0.023)	(0.028)	(0.021)	(0.023)	(0.027)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	2,892	2,892	2,892	2,892	2,892	2,892	2,892	2,892	2,892

Note: Dependent variables in all panels and columns are the within – students between – subjects differences in students' cognitive skills. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.9: Digital tools and students' motivation by gender.

	Female			Male			Diff.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Enjoy									
Digital tools	0.036	0.019	0.039	0.035	0.036	0.037	0.001	-0.017	0.002
	(0.020)	(0.023)	(0.027)	(0.020)	(0.022)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,565	2,565	2,565	2,411	2,411	2,411			
Boring									
Digital tools	-0.036	-0.023	-0.036	-0.034	-0.046*	-0.071**	-0.002	0.023	0.035
	(0.020)	(0.023)	(0.027)	(0.020)	(0.023)	(0.027)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,513	2,513	2,513	2,349	2,349	2,349			
Like									
Digital tools	0.047*	0.028	0.047	0.046*	0.046*	0.054*	0.001	-0.018	-0.007
	(0.021)	(0.023)	(0.028)	(0.020)	(0.022)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,510	2,510	2,510	2,359	2,359	2,359			
Favorite Subject									
Digital tools	0.056**	0.050*	0.051	0.056**	0.074***	0.083**	0.000	-0.024	-0.032
	(0.020)	(0.023)	(0.028)	(0.020)	(0.021)	(0.025)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,564	2,564	2,564	2,398	2,398	2,398			
Interesting things to do									
Digital tools	0.024	0.020	0.051	0.042*	0.027	0.051	-0.018	-0.007	0.000
	(0.020)	(0.022)	(0.026)	(0.020)	(0.022)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,557	2,557	2,557	2,397	2,397	2,397			
Subject will help me									
Digital tools	0.027	0.019	0.039	0.041*	0.042	0.066*	-0.014	-0.023	-0.027
	(0.020)	(0.022)	(0.026)	(0.020)	(0.023)	(0.027)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,565	2,565	2,565	2,383	2,383	2,383			

Note: We exclude all observations with missing information about students' motivation. Dependent variables in all columns are the within – students between – subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant.Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.10: Digital tools and students' motivation by parental education.

	High			Low			Diff.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Enjoy									
Digital tools	0.005	-0.007	0.000	0.081**	0.101**	0.075	-0.076*	-0.108	-0.075*
	(0.019)	(0.021)	(0.025)	(0.030)	(0.034)	(0.040)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,709	2,709	2,709	1,308	1,308	1,308			
Boring									
Digital tools	-0.003	0.002	-0.014	-0.087**	-0.103**	-0.119**	0.084 *	-0.105 ***	0.105**
	(0.019)	(0.021)	(0.026)	(0.030)	(0.033)	(0.040)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,654	2,654	2,654	1,268	1,268	1,268			
Like									
Digital tools	0.001	-0.013	-0.008	0.100**	0.107**	0.101*	-0.099**	-0.12***	-0.109**
	(0.019)	(0.021)	(0.025)	(0.031)	(0.035)	(0.042)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,649	2,649	2,649	1,284	1,284	1,284			
Favorite Subject									
Digital tools	0.015	0.018	0.019	0.105***	0.135***	0.121**	-0.009**	-0.117***	-0.102**
	(0.019)	(0.021)	(0.026)	(0.029)	(0.033)	(0.040)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,705	2,705	2,705	1,303	1,303	1,303			
Interesting things to do									
Digital tools	0.010	0.006	0.031	0.045	0.052	0.056	-0.035	-0.046	-0.025
	(0.019)	(0.021)	(0.025)	(0.029)	(0.032)	(0.039)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,705	2,705	2,705	1,299	1,299	1,299			
Subject will help me									
Digital tools	0.020	0.021	0.048	0.057	0.069*	0.089*	-0.037	-0.048	-0.041
	(0.018)	(0.021)	(0.025)	(0.030)	(0.034)	(0.041)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,699	2,699	2,699	1,298	1,298	1,298			

Note: We exclude all observations with missing information about students' motivation and the highest parents' education level. Dependent variables in all columns are the within − students between − subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.11: Digital tools and students' motivation by number of books at home.

	Many			Few			Diff.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Enjoy									
Digital tools	-0.003	-0.009	0.007	0.101***	0.095***	0.087**	-0.104***	-0.104	-0.08**
	(0.017)	(0.019)	(0.023)	(0.025)	(0.028)	(0.033)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,184	3,184	3,184	1,792	1,792	1,792			
Boring									
Digital tools	-0.001	-0.001	-0.023	-0.092***	-0.105***	-0.112***	0.091**	0.104***	0.089**
	(0.017)	(0.019)	(0.024)	(0.025)	(0.028)	(0.033)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,122	3,122	3,122	1,740	1,740	1,740			
Like									
Digital tools	0.009	0.001	0.016	0.113***	0.109***	0.111***	-0.104***	-0.108***	-0.095***
	(0.017)	(0.019)	(0.023)	(0.026)	(0.028)	(0.034)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,124	3,124	3,124	1,745	1,745	1,745			
Favorite Subject									
Digital tools	0.022	0.029	0.041	0.113***	0.119***	0.103**	-0.091**	-0.090***	-0.062**
	(0.017)	(0.019)	(0.023)	(0.025)	(0.027)	(0.033)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,176	3,176	3,176	1,786	1,786	1,786			
Interesting things to do									
Digital tools	0.005	-0.004	0.027	0.076**	0.069**	0.080*	-0.071*	-0.073**	-0.053*
	(0.018)	(0.019)	(0.023)	(0.024)	(0.026)	(0.032)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,172	3,172	3,172	1,782	1,782	1,782			
Subject will help me									
Digital tools	0.012	0.012	0.029	0.063*	0.052	0.069*	-0.051	-0.040*	-0.040*
	(0.017)	(0.019)	(0.023)	(0.026)	(0.028)	(0.034)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	3,174	3,174	3,174	1,774	1,774	1,744			

Note: We exclude all observations with missing information about students' motivation. Dependent variables in all columns are the within – students between – subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.12: Digital tools and students' motivation by number of digital information devices at home.

	Many			Few			Diff.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Enjoy									
Digital tools	0.048*	0.035	0.032	0.026	0.026	0.049	0.022	0.009	-0.017
	(0.021)	(0.024)	(0.028)	(0.019)	(0.021)	(0.025)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,105	2,105	2,105	2,849	2,849	2,849			
Boring									
Digital tools	-0.053*	-0.057*	-0.087**	-0.020	-0.020	-0.031	-0.033	-0.037	-0.056
	(0.022)	(0.024)	(0.029)	(0.019)	(0.021)	(0.025)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,062	2,062	2,062	2,779	2,779	2,779			
Like									
Digital tools	0.065**	0.055*	0.057*	0.031	0.024	0.046	0.034	0.031	0.011
	(0.021)	(0.024)	(0.029)	(0.019)	(0.022)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,061	2,061	2,061	2,786	2,786	2,786			
Favorite Subject									
Digital tools	0.075***	0.076**	0.061*	0.040*	0.051*	0.072**	0.051	0.025	-0.011
	(0.021)	(0.024)	(0.028)	(0.019)	(0.021)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,103	2,103	2,103	2,837	2,837	2,837			
Interesting things to do									
Digital tools	0.042*	0.031	0.049	0.024	0.017	0.053*	0.018	0.014	-0.004
	(0.022)	(0.024)	(0.028)	(0.019)	(0.021)	(0.025)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,102	2,102	2,102	2,830	2,830	2,830			
Subject will help me									
Digital tools	0.026	0.012	0.014	0.041*	0.045*	0.079**	-0.015	-0.033	-0.065
	(0.022)	(0.024)	(0.028)	(0.019)	(0.021)	(0.026)			
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	2,096	2,096	2,096	2,830	2,830	2,830			

Note: We exclude all observations with missing information about students' motivation. Students with "Many Devices" at home have more than ten digital information devices. Dependent variables in all columns are the within − students between − subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.13: Digital tools and students' overall achievement – Robustness.

	Variable			Average			Class size		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digital tools	0.007	0.013*	0.008	0.003	0.019	0.010	0.018	0.027	0.015
	(0.005)	(0.006)	(0.007)	(0.015)	(0.016)	(0.018)	(0.019)	(0.022)	(0.025)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	5,095	5,095	5,095	7,691	7,691	7,691	4,378	4,378	4,378

Note: Dependent variables in all columns are the within – students between – subjects differences in standardized test scores. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * p¡0.05, ** p¡0.01, *** p¡0.001.

Table A.14: Digital tools and students' cognitive skills – Robustness.

	Knowing			Applying			Reasoning		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variable									
Digital tools	0.010*	0.015**	0.010	0.005	0.012*	0.005	0.008	0.013*	0.006
	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)	(0.007)	(0.005)	(0.006)	(0.007)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	5,095	5,095	5,095	5,095	5,095	5,095	5,095	5,095	5,095
Average									
Digital tools	0.010	0.023	0.011	-0.002	0.013	0.000	0.004	0.018	0.006
	(0.013)	(0.014)	(0.017)	(0.013)	(0.014)	(0.016)	(0.013)	(0.014)	(0.017)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of students	7,691	7,691	7,691	7,691	7,691	7,691	7,691	7,691	7,691
Class size									
Digital tools	0.025	0.034	0.025	0.012	0.027	0.012	0.019	0.027	0.017
	(0.017)	(0.019)	(0.025)	(0.016)	(0.019)	(0.024)	(0.019)	(0.020)	(0.025)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,378	4,378	4,378	4,378	4,378	4,378	4,378	4,378	4,378

Note: Dependent variables in all columns are the within – students between – subjects differences in students' cognitive skills. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.15: Digital tools and students' motivation – Robustness.

	Variable			Average			Class		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Enjoy									
Digital tools	0.012*	0.008	0.013*	0.035**	0.022	0.037*	0.033*	0.024	0.032
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.015)	(0.016)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,976	4,976	4,976	7,529	7,529	7,529	4,280	4,280	4,280
Boring									
Digital tools	-0.012*	-0.011*	-0.019**	-0.040**	-0.038**	-0.053***	-0.040*	-0.036*	-0.053*
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.016)	(0.016)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,862	4,862	4,862	7,341	7,341	7,341	4,181	4,181	4,181
Like									
Digital tools	0.015**	0.011*	0.017**	0.040***	0.031*	0.044**	0.047**	0.036*	0.049*
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.015)	(0.016)	(0.017)	(0.022)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,869	4,869	4,869	7,353	7,353	7,353	4,179	4,179	4,179
Favorite subject									
Digital tools	0.019***	0.019***	0.022***	0.044***	0.045***	0.062***	0.052***	0.054**	0.059**
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.015)	(0.015)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,962	4,962	4,962	7,509	7,509	7,509	4,267	4,267	4,267
Interesting things to do									
Digital tools	0.010*	0.006	0.017**	0.041***	0.030*	0.064***	0.003	-0.005	0.017
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.015)	(0.015)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,954	4,954	4,954	7,492	7,492	7,492	4,259	4,259	4,259
Subject will help me									
Digital tools	0.011*	0.009	0.017**	0.038**	0.034**	0.062***	0.016	0.015	0.034
	(0.005)	(0.005)	(0.006)	(0.012)	(0.013)	(0.015)	(0.015)	(0.017)	(0.021)
Teacher controls		Y	Y		Y	Y		Y	Y
Class controls			Y			Y			Y
Number of observations	4,948	4,948	4,948	7,470	7,470	7,470	4,250	4,250	4,250

Note: We exclude all observations with missing information about students' motivation. Dependent variables in all columns are the within – students between – subjects differences in students' motivation. Different sets of controls are included (see A.2). Digital tools measures the frequency of using digital devices for different activities in classrooms. All regressions include a constant. Standard errors, reported in parentheses, are adjusted for the imputation variance. Significance is denoted by * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.