Is it the way they use it?
Teachers, ICT and student achievement

Simona Comi [a] [*], Gianluca Argentin[b] , Marco Gui[c] ,Federica Origo[d], Laura Pagani[e]

a. University of Milan-Bicocca, Piazza dell'Ateneo Nuovo 1, 20126, Milan, Italy. E-mail: simona.comi@unimib.it
b. Catholic University of Sacred Hearth, Largo Gemelli 1, 20123, Milan, Italy. E-mail: gianluca.argentin@unicatt.it
c. University of Milan-Bicocca, Piazza dell'Ateneo Nuovo 1, 20126, Milan, Italy. E-mail: marco.gui@unimib.it
d. University of Bergamo, Via dei Caniana 2, 24127 Bergamo, Italy. E-mail: federica.origo@unibg.it
e. University of Milan-Bicocca, Piazza dell'Ateneo Nuovo 1, 20126, Milan, Italy. E-mail: laura.pagani@unimib.it

Abstract

We provide evidence on whether ICT-related teaching practices affect student achievement. We use a unique student-teacher dataset containing variables on a wide set of very specific uses of computer and ICT by teachers matched with data on national standardized tests for 10th grade students. Our identification strategy relies on a within-student between-subject estimator and on a rich set of teacher's controls. We find that computer-based teaching methods increase student performance when they increase students' awareness in ICT use and when they enhance communication. Instead, we find a negative impact of practices requiring an active role of the students in classes using ICT. Our findings suggest that the effectiveness of ICT at school depends on the actual practice that teachers make of it and on their ability to integrate ICT into their teaching process.

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[*] Corresponding author. Tel.: +39 02 64487461.

1. Introduction

In the past two decades, Information and Communications Technology (ICT) has progressively acquired a prominent role in teaching and learning. Most countries have made huge public investments in the purchase and maintenance of ICT related educational devices. As a result, the majority of developed countries have reached high rates of school ICT access.

In 2009, 97% of the teachers in public primary and secondary schools in the US had one or more computers located in the classroom every day (93% of them with Internet access), and the ratio of students to computers in the classroom was 5.3 to 1 (Gray et al. 2010). In the same year, in Europe, at least 75% of the students had the availability of one computer for up to four students. The latest EU-survey on ICT in schools confirms that ICT has become more pervasive also in European countries. In the 2011-12 school year, there were approximately twice as many computers per one hundred students in secondary schools compared with 2006, and the share of schools with websites, e-mail for both teachers and students and a local area network has been steadily increasing at all levels of education (European Commission 2013).

In view of the large public outlays for ICT in schools in many countries, there has been an increasing research interest aimed at identifying the effect of ICT at school on learning, and scientific literature developed.

While most of these studies focus on the mere availability of ICT equipment in schools or on the use of computers (including specific software) to teach, in this paper we focus on a different aspect of this process, providing insights about the impact of a large set of specific ICT-related teaching methods on student achievement. The empirical analysis is based on a unique and rich matched student-teacher dataset developed in Italy, combining information from two *ad-hoc* ICT surveys, one administered to a sample of 10th grade students and the other to their teachers, with administrative data on standardized tests assessing the same pupils' achievement in math and Italian language.

A number of studies estimate the causal effect of ICT on students' performance by exploiting the exogeneity of national or local programs aimed at increasing ICT infrastructure in schools and find either little or no effect (Checchi et al. 2015, Barrera-Osorio and Linden 2009, Cristia et al. 2012, Goolsbee and Guryan 2006, Leuven et al. 2007). A partial exception is Machin et al. (2007), who investigate the effects of a change in the rules governing ICT funding across different school districts of England and find a positive impact on primary school students' performance in English and science, but not in mathematics. However, the above papers do not specify how ICT is used.

A few studies have gone beyond the analysis of the effects of the availability of ICT equipment and looked at the role of computer-aided instructions (CAI), such as the use of specific software programs to teach and promote learning. These studies often employ a dichotomous variable capturing the usage of CAI and generally find no statistically significant effects on student performance (Angrist and Lavy 2002, Rouse and Krueger 2004), except for mathematics achievement, particularly in early school years and where computers replace lower quality traditional instruction (Barrow et al. 2009, Banerjee et al. 2007, Bulman and Fairlie 2015).

Falck et al. (2015) is the only study analyzing the effect of three different classroom computer-based activities performed by students on their academic performance. They show that the null effect of classroom computers on student achievement is a combination of positive and negative effects of different computer uses.

Altogether, these findings appear to suggest that ICT use is not more effective than traditional teaching methods. A potential explanation is that the introduction of computers may have displaced alternative investments of school resources and the related educational activities which, had they been maintained, would have prevented a decline in student achievement. Another reason for the weak ICT effects in schools may be the difficulty to actually integrate ICT into educational practices. The availability of ICT-related educational devices (such as computers, tablets, software or educational programs) is not enough to improve student achievement, but it is the actual practice that teachers make of these devices – together with teachers' digital literacy, level of ICT skills and ICT-related beliefs – that makes the difference (OECD 2001).

The actual practice that teachers make of ICT and their ability to integrate it into the teaching process is then a key issue (UNESCO 2000), which may reconcile the existing mixed evidence on the effectiveness of ICT on student achievement. Indeed, educational research has clearly pointed out that teachers are crucial in determining the way ICT is adopted and used inside and outside the classroom (OECD 2015) and complementarities between ICT and teacher skills could counterbalance the negative effect on traditional instruction (Bulman and Fairlie 2015).

The importance of what teachers do in the classroom has been emphasized in the recent literature on the effects of teaching practices on students' academic performance, which has focused on the effect of traditional versus modern teaching style. The results generally show that teaching style matters (Aslam and Kingdom 2011, Schwerdt and Wuppermamm 2011, Zakharov et al. 2014), but the empirical evidence is not conclusive with regard to the comparative effectiveness of modern and traditional practices (Van Klaveren 2011, Lavy 2011).

Bringing together the literature on the effects of ICT at school and the literature on the effects of teaching practices on student performance, our paper makes a number of important contributions. First, we consider a great array of ICT-related teaching methods, covering a broad spectrum of teaching-related activities both in the classroom and outside, both with students and alone. The main contribution of our research builds on detailed questions asking the teachers how often they use computers for a wide array of teaching-related practices. On the basis of these questions, we identify five distinct groups of teaching practices: "backstage activities", such as preparing and printing files to be distributed in class; computer use for knowledge transmission during lessons, such as projecting slides or sharing files with students; teaching practices implying active involvement of students, for instance through the use of general or specific software; media education practices, such as teaching students how to use social media or blogs; and communication-enhancing activities, favoring teacher-to-teacher collaboration and communication with students and families.

Second, when estimating the effects of teaching practices on students' achievement, we control for both a subjective and an objective measure of teachers' digital skills. This latter is measured by means of teachers' scores in a detailed ICT performance test. Indeed, each practice might have a different effect depending on teachers' ICT knowledge, also because the lack of it could make teachers anxious, primarily in classrooms of students whose ICT knowledge is higher than their own. Moreover, we have information regarding past ICT-related training, which may affect both teachers' ICT knowledge and its pedagogical use through specific practices.

Third, an important factor we are able to control for are teachers' beliefs about ICT use for teaching and learning. Existing evidence demonstrates that these latter affect the frequency of ICT use in schools more than the availability of infrastructures: students taught by teachers who are positive about ICT use in education but face low access and high obstacles to utilizing it at school report more frequent use of ICT during lessons compared to students taught by teachers having high access to ICT but being less positive about its usefulness for teaching (European Commission 2013).

Finally, thanks to the availability of information for two subjects for the same students, as in previous contributions in the literature we adopt an identification strategy that exploits within-student between-subject variation to control for unobserved students' traits. Moreover, differently from previous studies based on countries, such as the US, in which students can self-select into classes within schools, the specific Italian institutional setting, prohibiting class choice within schools, helps us circumvent the potential non-random sorting of students to teachers because the actual student-teacher match within school is substantially random.

We find that the effect of the computer-based teaching practices outlined above is quite heterogeneous. They increase student performance primarily if they are used to teach students a critical use of the Internet or to support communication with students, families and colleagues. On the contrary, a negative effect is found for practices requiring more active involvement by students in classrooms. We also find heterogeneous effects of computer-based practices by subject (Italian language and math).

Our results are not driven by specific groups of teachers, such as those who strongly believe in the usefulness of ICT for teaching or those who are very familiar with it.

In the case of practices requiring active involvement of students in classrooms, we obtain similar results using an alternative dataset that allows to fully control for teacher subject-invariant characteristics exploiting within-teacher within-student variation.

The remainder of the paper is structured as follows: the next section describes the data and the main variables used in the empirical analysis; Section 3 presents a description of the computer-based teaching methods that we consider, and it provides some theoretical insight into their potential effects on students' learning; Section 4 explains the identification strategy, also paying attention to the specific institutional setting of the Italian school system; Section 5 presents the main results; a number of robustness checks and extensions are discussed in Section 6. Concluding remarks and some policy implications are provided in the last section.

2. Data and descriptive statistics

In this paper we use a unique dataset based on three different data sources: two ad-hoc surveys, conducted simultaneously - one on 10th grade students and one on their teachers- and an administrative data-set about their performance in Italian language and math at the national standardized assessment, occurring at the end of the same school year. We merged the three datasets at student individual level.

Student survey

The first data-source is an *ad hoc* ICT survey conducted on a representative sample of students in their second year of upper secondary school (10th grade) in the Lombardy region, the most populated and economically advanced region in Northern Italy. The survey was conducted in April 2012 on a sample stratified by school type and geographical (provincial) position. The response rate of the sampled schools was 94%. None of the students present during the administration of the survey refused to fill the questionnaire. The final sample contains 2,025 students from 100 classrooms randomly drawn from 51 randomly selected upper secondary schools. We collected standard information on socio-demographic characteristics, on past and current academic performance[1] and on extra-curricular activities.

Teacher survey

The second data-source is another *ad hoc* survey conducted on all the teachers of the 100 classrooms covered with the first survey. The survey was web-based and about 634 teachers answered. We collected information on teachers socio-demographic characteristics (gender, birth year, highest education level obtained, field of study and graduation grade), job position (experience, tenure, type of contract, the number of hours taught weekly and the subject taught), training (including ICT-related one) and the reasons for choosing a teaching career, which we employ as a proxy for motivation. The questionnaire specifically focuses on teachers' use of ICT outside of their jobs, asking how frequently they use a computer, how many hours they spend on the Internet daily and whether they have a Facebook profile. The most relevant part of the survey for our research asks teachers how often they use computers for a wide array of teaching-related practices, such as creating and projecting slides during classes, assembling digital material to be delivered to students, showing students specific educational websites or using a PC to communicate with colleagues, students and their families. The teachers are also asked whether they use educational software and whether they help students with ICT-related problems or explain how to conduct an Internet search using encyclopedias or websites. Then, teachers report how many hours per month they utilize an interactive whiteboard, a PC with a projector or a PC to work outside of the classroom. The final part of the questionnaire relates to teachers' opinions about the use of ICT as a tool to facilitate learning and asks for a self-evaluation of their ICT-related knowledge.[2]

At the end of the survey, a standardized test is administered to assess some of the main aspects of teachers' digital knowledge. The test has been developed by educational and ICT experts and it is an updated version of the test already used with students in Gui and Argentin (2011). The test consists of 15 closed-ended questions, focused to assess the "critical digital skill", that is, (teachers') ability to assess the reliability of webpage content or to identify correctly the sources and the risks related to Internet use. More specifically, teachers were asked to analyze

[1] Among other questions, we asked each student the average grade obtained in Italian language, math, foreign language and science at the end of the first term of the same school year (February).

[2] The specific question is as follows: *All in all, do you think you are prepared to use the new ICTs as a teacher? Please answer using a 10-point scale (where 1 is not prepared at all, 10 is absolutely prepared).*

website addresses and browser search results and to prove their knowledge of the functioning of popular websites among youth, such as Facebook, YouTube, Yahoo Answers or Wikipedia.[3] We computed a normalized score describing teachers' digital knowledge based on the number of correct answers provided in the test.

Administrative data on national standardized tests

In order to get "objective" information on student achievement, we used administrative data from the Italian National Institute for the Evaluation of the School System (INVALSI), which administers standardized tests in order to assess pupil achievement. INVALSI tests are administered to all Italian students in their 2nd, 5th, 8th and 10th grades in May, at the end of the school year. These tests were introduced in Italian schools in 2008, with the aim to provide a statistical framework on student achievement to both policy makers and school principals. Math and Italian language constitute the subjects tested and they serve as key indicators of student performance. Being the students in our main sample in their 10th grade, they all took the INVALSI test at the end of the 2011/2012 school year, the same when the ICT surveys were conducted.[4]

From the INVALSI source, we extract our dependent variables: the math and Italian language test scores. We use also the standard pupils' questionnaire submitted along with the test, which contains additional information on students (such as their level of confidence with questions such as those usually asked in the national tests). These administrative data were individually merged with our ad hoc students survey using demographic information about each student.[5]

[3] Examples of questions are the following two: 1*) In your opinion, who writes Wikipedia entries? Choose only one of the following four possible answers: a. Those who are registered on the Wikipedia website and were accepted as collaborators; b. The creators of the website and other paid employees; c. There are no limitations: anyone can write them; d. Only a pool of experts chosen by Wikipedia.* 2) *Are the following sentences true or false? a. When you publish something on Facebook, you can make it accessible only to some of your Facebook friends; b. Information on Yahoo Answers is reliable because published answers were checked by experts; c. You can sign a contract with YouTube to get money for the videos you upload*.

[4] Only the score of the tests taken at the end of the 8th grade, in June, officially contributes to the final mark of the national exam the students have to take at the end of junior high school. Furthermore, INVALSI should test not only students' knowledge, but a large set of skills that students should acquire at school over time, including how they use the acquired knowledge to deal with practical problems. Both tests may contain multiple choice and open questions, from which a comprehensive score is computed, as in PISA and TIMMS. There is no evidence that either students' ICT knowledge (Gui, 2013) or ICT investments in schools (Checchi et al, 2015) significantly improve students' INVALSI test score.

[5] This information was anonymous, but coded.

Sample selection and descriptive statistics

Starting with our original sample of 2025 students (100 classrooms), we drop those students for whom we were not able to either observe or match the national standardized test scores, ending up with 1466 students (84 classrooms). We then selected only the students whose both Italian language and math teachers filled out the teacher questionnaire. Our final sample contains 868 students (47 teachers/ classrooms), for a total of 1736 student/subject observations.

Our final sample does not differ from the original one with regard to the main students' characteristics. In particular, both the average grade in the first term of the school year and the average national test score are not statistically different in the two samples.

Panel A of Table 1 reports the main descriptive statistics of a set of standard teacher characteristics by subject. Italian language teachers, compared with math teachers, are slightly younger and more educated and graduated with higher marks and, not surprisingly, they teach more hours per week in the considered classes. When we look at the choice of becoming a teacher, we can see that approximately 33 percent of Italian language teachers and 47 percent of math teachers pursued this career because of their passion for the subject. Conversely, 44 percent of Italian language teachers and 36 percent of math teachers chose this career because they wanted to teach or work with young people. The remaining share in each sample became teachers because of the lack of other job opportunities or because that type of job was responding to their own needs.

TABLE 1 AROUND HERE

Table 1 (Panel B) also highlights that, on average, students in our sample perform better on the national test of Italian language than that of math: as clearly shown in Figure 1, the within-student difference in the test scores is almost always positive (only 8% of the students exhibit a better performance in math). Consistently, the average grade in the first term is slightly higher in Italian language than in math. A number of explanations are consistent with this result: for example, students may be more competent in Italian language than in math or the first may be an easier subject than the latter. Furthermore, in Italy, it may also be the case that students are better trained in Italian language than in math to answer questions such as those on the national test. Actually, 45 per cent of the students in our sample have declared being familiar with the type of questions usually asked on the national test of Italian language, while the corresponding share for math drops to 26 per cent (see Table 1, Panel B). [6]

To address this issue and make the score in the two subjects comparable, as done in previous studies, we standardize the national test scores by subject (Aslam and Kingdom 2011). We will employ this standardized variable as the dependent variable of the following econometric analysis.

FIGURE 1 AROUND HERE

In Table 2, we focus on teacher ICT variables by subject. Quite interestingly, Italian language teachers performed on average better than math ones in the test on critical digital knowledge, but their subjective perception is lower. Compared to math teachers, Italian language teachers have a lower probability of attending an ICT-related training course, spend more hours on the Internet, and have a higher propensity to use a PC every day at home and to have a Facebook profile. A great majority of Italian language teachers believe that ICT is useful in preparing lectures, while only approximately one-half of math teachers share this opinion. Regardless of the subject taught, two out of three teachers are in favor of ICT use in teaching, and one out of three thinks that ICT introduced an important change in teaching. At the same time, only 15 percent of math teachers and 5 percent of Italian language ones believe that ICT had a positive effect on one's own teaching. A greater percentage of math teachers feel that their school is in favor of ICT introduction, while a greater share of Italian language teachers perceive some type of hostility.[7]

Finally, Italian language teachers use the interactive whiteboard (IWB) while teaching fewer hours per month and the PC with a projector more hours per month than math teachers do. There is no difference in the use of a PC in class on their own.

TABLE 2 AROUND HERE

[6] Written math exams in Italian secondary schools are generally open questions or standard problems, while they rarely test problem solving and logical thinking, which are instead the core skills tested in most questions of the national test of math.

[7] The reference category here is teachers who perceived neither hostility nor encouragement towards the introduction of ICT in their own school.

3. ICT-related teaching practices

ICT-related teaching practices have been so far almost unexplored in the economic literature, but the educational literature provides some theoretical insight and evidence on their potential effects on students' achievement. We refer to this literature to interpret the empirical results presented in the following sections.

The first use teachers can do of ICT is to prepare slides and other material, including tests, to be used in the classroom. These ICT-related "backstage activities" may have a positive impact on students' learning because they help making lessons more complete and attractive thanks to the enormous and easily available set of textual and audiovisual contents. In addition, ICT can help teachers to customize their teaching more effectively, i.e. helping them to personalize students materials. This idea is supported by the evaluation of the "Laptops for teachers" program of the British Government (2002-2004), where teachers who had been equipped with laptops report having extended their ability to access resources and having saved time in lesson planning and preparation (Cunningham et al. 2003). Furthermore, teachers believe that preparing their lessons online has positive effects on the quality of their teaching (Ramboll Management 2006, Condie and Munro 2007).

A number of studies investigate the effect of the use of pc and ICT in class and show that computer use during lessons as a support for teachers pushes them to plan their lessons more efficiently (Higgins et al. 2005, Balanskat et al. 2006) and makes lessons more attractive for students (Ramboll Management 2006, Balanskat et al. 2006), clearly improving intermediate outcomes such as motivation and behavior (Condie and Munro 2007). The "visual appeals" of projected presentations appear to be the main contributor to this improvement (Smith et al. 2006). However, some have cast doubts on the persistence of this association, claiming that a "novelty factor" could be at work and that, consequently, the effect could vanish when technology in schools is no longer a novelty (Digregorio and Sobel-Lojeski 2009).

The presence of ICT in the classroom is likely to facilitate a debate between students and their teachers on digital risks and opportunities, whose level of awareness seems particularly poor among adolescents (Calvani et al. 2012, Gui and Argentin 2011, Van Deursen and van Dijk 2009). There is also evidence that digital supportive teachers tend to have more digitally aware students (Argentin et al. 2013) and that, in turn, a higher level of students' critical digital skills has a positive impact on their learning outcomes (Pagani et al. 2015).

Evidence on ICT-related practices requiring students' active involvement demonstrates that teachers usually do not fully exploit the creative potential of ICT, for instance engaging students more actively in the production of knowledge (Balanskat et al. 2006). The active use of ICT by students during lessons actually opens unexplored horizons in the student-teacher relationship. Maybe due to the complexity of the re-organization of teaching and classrooms that an active use of ICT in the classroom demands, no evidence of positive impacts have emerged so far. On the contrary, a number of studies have actually found a negative association between learning outcomes and the frequency of ICT use by students at school or for school-related purposes (OECD 2011, Biagi and Loi 2013).

ICT can be used in teaching also for communication purposes. Research on the evaluation of ICT investment educational policies demonstrates that pupils and teachers appear to benefit from ICT-related communication practices between school and families (Condie and Munro 2007), and teachers perceive positive effects on teaching quality when ICT is employed to enhance communication with the other colleagues (Ramboll Management 2006). Nonetheless, only a small proportion of teachers, even when they make extensive use of ICT, report that they exploit the new technologies to increase collaboration with their colleagues, for instance co-producing knowledge with other teachers inside and outside the school (OECD 2001).

Finally, educational literature has been traditionally investigating how teacher should use ICT to teach different subjects, but there is not a clear consensus yet about which subjects benefit more from ICT or which practice is better than any other in each subject. According to some contributions, ICT may fit in with some school subjects more easily than others and computers are traditionally perceived as a domain closely related to mathematics and science (Goodson & Mangan, 1995). Specific software and simulations are typically associated with scientific subjects, while visual approaches in presenting learning material are more frequent in teaching humanities. On the other hand, in describing a “call to action” for ICT introduction into teaching, Voght et al (2013) claim that in principle the mediating role of ICT in teaching and learning does not differ much across subjects. They stress out the importance of other factors (such as teacher ICT knowledge, teacher confidence and beliefs) in influencing ICT adoption and call for more research on competencies needed to teach (and learn) different subjects with ICT.

Identifying ICT-related teaching practices

With regard to the use of ICT in teaching, we asked teachers how often they used their personal computer to conduct 19 specific activities while preparing for or during classes. For each question, we report the distribution of answers separately for the two subjects in Table A1 in the Appendix. The overall picture is rather rich and heterogeneous. Some of the practices are widely diffused, such as preparing tests or printouts, while other are very infrequent, such as enrolling in online training courses. Some practices display wide differences by subject: for example, it is more likely that math teachers use educational software than Italian language ones, while the contrary is true when we look at preparing printouts or teaching how to use an online encyclopedia.

These practices are clearly correlated with one another for several reasons, such as the school policy towards the use of ICT in teaching, the nature and contents of the subject taught, individual teaching style and other teacher characteristics. To summarize the great amount of available information, to take into account the existing bundles of practices, and to ease interpretation of the main results, we run a Principal Component Analysis (PCA) on the original sample of approximately 600 teachers, those that answered all of the items considered in the analysis. This approach builds on that used by Kane et al. (2011). We kept the first five components that emerged from the analyses, those with an eigenvalue greater than one (a standard criterion). This model is acceptable and explains 62% of total variance. Table A2 in appendix provides some statistics for each of these first five components, together with their eigenvalues and the proportion of the total variance explained by each factor. The lowest communality is 0.38, and each item is strongly associated only with one component. [8] Table 3 reports the associations between each item and the five components.

TABLE 3 AROUND HERE

The first component loads practices that imply the use of a personal computer during lessons, such as using slides or other digital material (video, audio or website) in class or sharing files with students (not printed or to be printed), so that ICT is employed to deliver information more efficiently, and that is why we named it *knowledge transmission* practices. The second component, labelled *media education,* loads practices aimed to produce skills that are not directly linked to the subject, such as the awareness of digital risks (evaluation of website

[8] There are three exceptions. "Use of internet to prepare lectures" enters both the backstage activities and the use of pc in class, while "Teach how to avoid viruses" and "Teach how to evaluate the dependence of website content" are associated with media education and active involvement of students in class. The nature of these practices justifies their association to more than one component and makes these double associations very reasonable.

content or how to avoid viruses), privacy rules or netiquette in social media. The third component loads practices requiring an interaction among the teacher, the students and ICT devices, such as utilizing common or specific software in class, explaining how to study with the Internet or how to consult an online encyclopedia. Indeed, these are activities in which each student is "activated", i.e., assisted by the teacher in utilizing the technology to reach a particular goal, such as writing text or solving an equation. We labelled this factor *active involvement*. The fourth component loads background practices usually performed out of the classroom, such as preparing printouts, tests or lectures, and we call it *backstage activities*. Finally, the last component, labeled *communication*, pertains to the communication aspect of ICT, such as utilizing e-mail to communicate with students, family or colleagues or reading online formal communication by the ministry or the school board.

Table 4 reports the means of the five components by subject. In our sample, math teachers tend to use more frequently not only *active involvement* practices, but also *knowledge transmission* and *communication* practices. On the contrary, Italian language teachers use more ICT for *backstage activities* and *media education*. This descriptive evidence confirms the existence of heterogeneity in the use of ICT practices by subject, but these differences are less clear-cut than those emphasized in early studies in educational literature and are likely to be influenced by teacher characteristics, including their ICT knowledge and beliefs.

TABLE 4 AROUND HERE

Furthermore, according to the evidence provided by the educational literature, these practices should have heterogeneous effects on student achievement. While backstage activities and practices aimed at knowledge transmissions should positively affect students' performance by improving both the quantity and the quality of the material teachers use to prepare their lessons, practices requiring a more active involvement of the students in using the PC or Internet while in the classroom appear to be rather distracting and time consuming, with potential negative effects on students learning. A positive effect may be also associated to the use of ICT-related communication practices, as long as they allow the teachers to be more effective in communicating with the students, get further teaching material from colleagues or save time that can be invested in more productive teaching activities. No direct evidence is available on media education practices and students learning. However, evidence on teachers' ICT-related beliefs and students' digital awareness suggests that such practices can positively influence students' learning if digitally aware students use Internet more effectively and/or save time that can be used to improve learning. On the contrary, debates on these issues in the classroom may be very time consuming and steal time to more productive activities for student achievement.

4. Empirical strategy

To assess the effect of ICT-related teaching practices, we consider the following specification of the standard education production function:

$$y_{ijk} = \alpha + \beta_1 ICT_{ijk} + \beta_2 X_{ijk} + \beta_3 S_{ijk} + \beta_4 T_{ijk} + \varepsilon_{ijk} \qquad [1]$$

where y is the test score of student i in subject j in school k, ICT is a vector of variables measuring teacher ICT-related practices, X is a vector of student characteristics, S is a vector of school characteristics, and T is a vector of teacher (and class) characteristics.

The error term ε captures all of the unobserved factors influencing student performance, and it can be specified as follows:

$$\varepsilon_{ijk} = \mu_i + \theta_j + \varphi_k + v_{ijk} \qquad [2]$$

where μ, θ and φ are, respectively, student, teacher and school time-invariant unobserved factors. With a specification with school, teacher and student fixed effects, identification comes from a differential use of ICT for the same student with the same teacher within school.

Estimation of equation [1] by OLS yields biased estimates if the unobserved factors are correlated with the variables in the ICT vector. This may be the case when neither teachers nor students are randomly distributed across schools (and across classes within schools) or when the adoption of ICT teaching practices is influenced by teachers' unobserved characteristics that also affect student achievement. Endogenous sorting may arise because families choose specific schools for their children, also on the basis of the teacher's quality and reputation. There is evidence, regarding USA, showing that teachers prefer to work in schools with higher-achieving students, while they have heterogeneous preferences in terms of other students' observable characteristics, such as race and ethnicity (Hanushek 2004). Schools that are able to employ more effective teachers can in turn attract the highest achieving students and, hence, the unobserved students' heterogeneity is likely to inflate differences between schools in teacher quality. Despite this evidence of positive sorting between "good" teachers and "good" students, predicting the direction of the actual bias is difficult because, within schools, it also depends on the principal's objectives and decisions (Hanushek and Rivkin 2012): an egalitarian principal would place the higher quality teachers in classes with more disruptive children, while a principal who wants to retain the senior staff would match the more experienced teachers with the best students.

In our case, the specific institutional setting characterizing upper secondary education in Italy allows us to partially address the problem of endogenous matching between teachers and students: once families choose the school for their children[9], the latter are usually assigned to a certain class regardless of families or children's preferences for specific teachers or schoolmates, due to the fact that the Italian law prescribes this. The class is not identified by a certain grade, but by a subsection of a certain year. In order to have "equally heterogeneus" classes, principals of public schools usually group entering students with different ability and background (Poletto 1992). Similarly, the principal defines the teaching teams by grouping teachers with different ability, qualification and experience. Each class is then substantially randomly matched with a certain teaching team. Furthermore, the class is the same for all of the subjects taught and for the entire duration of high school: minor changes each year are due to students who have to repeat a year (a fact happening frequently in Italian high schools) or who change school (a rare event) or who move to another town (an exceptional event). In this perspective, the same group of students (and teachers) could expect to be together for five years. Each class does everything together, staying all day in the same room; it is the teachers who go from classroom to classroom, except the few ones whose subjects require labs or other special equipment. Everyone in a class takes the same courses because there are no electives in Italian high schools: the pool of subjects is determined by the type of high school and program initially chosen. If the student realizes that this is not what she is really interested in, she will change the program or even the school. This is usually done by the end of the first year of high school (i.e., 9th grade) because later changes are usually very costly in terms of needed prerequisites for entering the new program/school, often requiring starting again from the first year.

Although the features of the institutional setting attenuate the problem of sorting between students and teachers, student achievement may be influenced by (unobserved) student, teacher and school factors. To address these sources of endogeneity and completely rule out selection between and within schools due to student unobservable characteristics, we follow the approach

[9] Checchi and Flabbi (2007), on the basis of the PISA 2003 dataset, show that in Italy sorting across schools (and academic tracks) is driven more by family background (parental education and occupation) than by ability (test scores, grade repetition, previous marks). In our specification this type of sorting should not be relevant, since we control for school fixed effects and family background using a within-student between-subject estimator.

proposed by Dee (2005, 2007) and employ a within-student between-subject estimator, which allows us to fully control for the unobserved heterogeneity of schools, classrooms and students. We then take differences between two subjects (in our case, Italian language and math, named I and M, respectively) in the following way:

$$y_{iIk} - y_{iMk} = \alpha_I - \alpha_M + \beta_{1I}\, ICT_{iIk} - \beta_{1M}\, ICT_{iMk} + (\beta_{2I} - \beta_{2M})X_i + (\beta_{3I} - \beta_{3M})S_i + \beta_{4I}T_{iIk} - \beta_{4M}T_{iMk} + \omega_i \qquad [3]$$

where: $\omega_i = (\theta_I - \theta_M) + (v_{iI} - v_{iM})$ [4]

If we assume, as in Dee (2005), that the coefficients across subjects are equal[10], equation [3] reduces to:

$$y_{iIk} - y_{iMk} = \alpha_I - \alpha_M + \beta_1\, \Delta ICT_i + \beta_4 \Delta T_i + \omega_i \qquad [5]$$

where identification of the coefficients relies on differences between subjects for the same student and on uncorrelation between the error term and the right hand side variables. This is equivalent to estimate a fixed-effect model with all the regressors in levels and a subject dummy, which will be the estimator we shall use in the following tables. [11] Note that the second term in brackets of the error term in equation [4] may still contain student subject-specific unobserved factors (such as a differential aptitude toward each subject), which influence student performance and can be correlated with ICT teaching practices. To consider this potential source of endogeneity, we add to equation [5] some subject-specific student variables, namely the grade in the first term of the year in each subject, the familiarity with questions like those usually asked in the national tests and their beliefs relative to the importance later in life of each subject. [12]

[10] As in previous studies, we allow the constant to differ across subjects.

[11] In traditional panel data, with time periods instead of subjects, this is like the equivalence between a first difference estimator and a fixed effects one with two time periods (see Wooldridge 2010). Starting from Dee (2005, 2007), the within-student between-subject estimator has been widely used to account for selection effects in studies on the effect of teaching practices (Aslam and Kingdom 2007, Schwerdt and Wuppermann 2011, Van Klaveren 2011, Lavy 2015 and Falck et al. 2015).

[12] We claim that these set of variables should control for subject-specific characteristics that potentially survive the student fixed effect estimation. As further support to this claim, we

Using this estimator, we fully control for both school and class unobserved heterogeneity, but we cannot rule out potential endogeneity caused by unobserved teacher-specific factors. We address this problem exploiting the richness of the survey and controlling for a number of teacher characteristics (such as gender, age, education, training, work experience, tenure, type of contract, weekly hours taught), including some controls usually not available in previous studies, such as a proxy for teacher's innate ability (captured by their graduation grade) and for their motivation (captured by the main reason for which they chose to become teachers).

It should be stressed that Italian teachers are autonomous in their choice to introduce ICT-related teaching practices.[13] On the one hand, such freedom in choosing teaching tools allows the variation across subjects that is needed for identification. On the other hand, as mentioned above, it may be a crucial source of endogeneity of ICT-related practices related to self-selection of teachers into ICT adoption. In fact, those who employ ICT are likely to be teachers with more (unobservable) easiness with, love for, and ability with ICT, or strong beliefs on the effectiveness of ICT in teaching; these characteristics may also influence student achievement – or they may be correlated with other unobservable characteristics that affect student achievement. This would lead to biased estimates of the coefficient β_1 in equation [5]. We address this issue in three ways. First, we control for the teacher ICT use and knowledge, both subjective and objective, for teacher beliefs on ICT usefulness, for their beliefs on the efficacy of specific ICT practices and finally for their perceptions about whether their school encourages or not ICT adoption. We thus consider a large set of factors that are in the unobserved component of the teacher specific error term and that could be related to the confidence of teacher in adopting ICT teaching practices. In fact, according to many studies in the educational literature, teacher skills, their attitude (expression of "will") and their access to technology are the key predictors of teacher ICT adoption (Christensen & Knezek 2008; Scherer et al. 2015). Perceived usefulness can be considered a behavioral belief, which forms the prerequisite for acting out behavior (Chien et al. 2014). The perceived usefulness of ICT in teaching appears to be affected also by self-efficacy: teachers who perceive themselves as competent in utilizing

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estimated equation [1] with classrooms fixed effects and the set of subject-specific variables. We then took the residuals and found no statistically significant differences in students score between any pair of classrooms. Estimates are available upon request.

[13] Freedom in teaching is a general principle set out in the Italian Constitution, although the choice and use of teaching methods and materials must be consistent with each school's educational plan, which, in turn, must be consistent with the general and educational objectives (also regarding ICT skill) of the different branches and levels of study established at national level. In order to safeguard freedom in teaching, teachers can choose textbooks and teaching tools.

ICT perceive the use of ICT as useful. Moreover, this relation stresses the importance of teachers' perceptions of their competences for their intention to use ICT (Lee and Lee 2014). Finally, school environment plays a key role in creating incentives for ICT adoption. Teachers work not in isolation, but as part of a socio-cultural environment that encourages or inhibits the use of ICT (Somekh 2008).

In our richest specification, the coefficient β_1 should gauge the "net" effect of specific ICT-related teaching practices on student achievement, since its identification comes from a different use of these practices by different teachers for the same student, after taking into account student subject varying characteristics, teacher characteristics and potential self-selection of teachers into ICT adoption (on the basis of their beliefs and behaviors). We obviously acknowledge that our strategy may not be able to control for all the unobserved characteristics that may influence ICT adoption by teachers. Nonetheless, it should be considered that we are able to correct this bias for an unusually wide set of control variables.

Then, we run robustness checks to test whether our main results are driven by teachers who are more familiar with the use of ICT or with stronger beliefs on the importance and usefulness of new technologies in schools and teaching.[14]

Finally, we estimate equation [5] employing a different dataset, TIMMS 2011, in which we have students' science and math test scores for the last year of junior high school (8^{th} grade). In this grade, in Italy, the same teacher teaches these two subjects, so we can add to the specification a teacher fixed effect and control for those unobservables components of teacher traits that may affect both ICT adoption and student achievement.[15]

As a final point, one could argue that the assumption of equal coefficients across subject used to derive equation [5] may be unrealistic, and the effect of different ICT teaching practices may be quite different in math and Italian language. For example, using specific software may be more effective in teaching math, while teaching how to consult a media encyclopedia may be more relevant for learning Italian language. To consider a potential heterogeneous effect of different ICT teaching practices by subject, we relax the assumption of a common treatment effect and estimate the following more flexible specification:

[14] As mentioned above, ICT use and beliefs are among the controls for teacher characteristics in the main estimates. In the robustness checks, we use these characteristics to split the sample and test the existence of heterogeneous effects by types of teachers.

[15] This is not the case in upper secondary schools, where math and science are taught by two different teachers. Hence, even if we had data on the science teacher, we could not control for teacher fixed-effect with our data.

$$y_{iIk} - y_{iMk} = \alpha_I - \alpha_M + \beta_{1I}\, ICT_{iIk} + \beta_{1M}\,(-ICT_{iMk}) + \beta_4 \Delta T_i + \omega_i \qquad [6]$$

where all of the variables have the same meaning as in equation [5], but we allow the effect of ICT teaching practices to differ across subjects.

5. Results

Table 5 presents main estimates of equation [5] using the ICT-related practices we computed from the principal component analysis. We cluster standard errors at the classroom level throughout the paper. Since we used standardized measures of each component, we can interpret the reported coefficients as the effect of a one standard deviation increase in that component on student achievement. We first consider just the five set of ICT-related teaching practices (column 1), and then progressively add sets of control variables. In column 2 we add a set of standard teacher characteristics (gender, age, education, college final grade, a polynomial of the second order for experience and tenure, weekly teaching hours and their motivations) and teacher ICT-related variables (subjective and objective ICT knowledge, how much they use technology and whether they attended an ICT-related training course). We then progressively add additional controls for teachers' ICT-related beliefs and perceptions. First, in column 3 we control for beliefs on the general importance of ICT in teaching (whether the teacher thinks that ICT is important in teaching and whether it is important in the subject she teaches). Then in column 4 we include controls for perceived school environment toward the use of ICT (whether the teacher thinks her school/colleagues are in favor of or hostile to ICT adoption). Further, in column 5 we add a set of beliefs on specific ICT teaching practices (whether the teacher is in favor of ICT use in preparing lectures, whether the teacher is in favor of ICT use in teaching, whether the teacher is in favor of ICT use involving students). Finally, in order to take into account the potential residual endogeneity not captured by student fixed effects, we control for students' subject-specific characteristics (mean grades at the end of the first term, familiarity with INVALSI-type tests and motivations to study each subject).[16]

[16] It may be argued that grades at the end of the first term may be already influenced by ICT teaching practices and the inclusion of this control can partly capture the overall effect of ICT teaching practices on student achievement. In our preferred specification, this variable should capture initial differences in performance in the two subjects. To test the sensitivity of our estimates, we re-estimated our preferred specification also excluding this control. Our results do no change when we exclude the grade in the first term from our specification.

Estimates in the first column show that ICT teaching practices do not significantly influence student achievement, with the exception of communication practices, which seem to improve it. These findings are robust to the inclusion of teacher characteristics. However, a quite different picture emerges when we control for teacher's beliefs related to the use of ICT in teaching. Once controlling for general beliefs, we find that also media education practices significantly improve student performance, while a negative effect is caused by practices requiring an active involvement of the students. Estimates do not substantially change when we control also for teacher perceptions on school environment (if any, they are statistically more robust), while the inclusion of beliefs on the efficacy of specific practices increases both the negative effect of practices requiring an active involvement of the students and the positive effect of communication-enhancing practices and knowledge transmission, but the latter remains not statistically significant. The inclusion of students' subject-specific characteristics does not change these results, except for increasing the precision of the estimated positive effect of practices related to knowledge transmission, which indeed turns out to be statistically significant only in the last specification. Hence, results for the latter set of practices seem less robust than those found for the other factors.

Regardless of the specification used, the estimated coefficient for backstage activities is never statistically significant. Furthermore, once we start controlling for teacher beliefs (i.e., in columns 3-6), we find that the five factors are jointly significant (as shown by the F-tests at the bottom of the columns).

Regarding the magnitude of the effects, our estimates in column (6) show an increase of one standard deviation in ICT-related practices enhancing communication is associated with an increase in student's test score of slightly less than one third of a standard deviation, corresponding to a 4.5 increase on a 100-point scale. A similar increase in practices aimed at developing the critical use of ICT causes an improvement of the test of approximately one-fifth of a standard deviation. On the contrary, an increase of one standard deviation in the practices requiring active involvement of the student in the use of ICT in the classroom reduces the test score by almost 30% of a standard deviation. [17] This result confirms that – at current conditions

[17] We tested linear combinations of different coefficients. Our estimates imply that, other things equal, the simultaneous implementation of practices requiring active involvement of the students with those increasing critical digital skills does not significantly influence student achievement. The same occurs if the first set of practices is implemented with those enhancing communication. Furthermore, a simultaneous increase in the use of the latter and those improving student digital skills has a very large impact on student achievement (almost half of a standard deviation, corresponding to almost 8 points on a 100-point scale). We acknowledge

- there could be a decrease in learning performance when ICTs are used intensively by students at school (OECD 2011).

The estimated effect of introducing ICT-related teaching practices is rather large, but comparable with that found for other popular education policies, such as class size reduction. According to recent reviews covering a large number of studies (Chingos 2012; Jepsen 2015), the effect of reducing the class size by ten students on test scores ranges from zero to almost half standard deviation. However, reducing the class size is a very expensive policy and may cause a number of unintended effects, such as a lower teacher quality due to the need of hiring less experienced teachers to cover a larger number of classes (Jepsen and Rivkin 2009). Hence, compared to class reduction, the implementation of policies to foster ICT-related teaching practices is much less costly and should have no unintended effects in terms of teacher quality, but requires a relevant additional teachers' effort.[18] They should invest hardly in training, but previous evaluations of professional development interventions involving Italian teachers showed that they are characterized by low level of compliance (Argentin et al 2014).

TABLE 5 AROUND HERE

To sum up, ICT-related teaching practices increase student performance if they improve also their digital awareness or critical digital skills and if they accelerate or make it easier teachers' communication with students, families and colleagues. They are also likely to be beneficial if they support knowledge transmission, albeit results are sensitive to model specification. On the contrary, they do not significantly affect student performance if they help the teacher to obtain further material to prepare her lectures and they may actually be detrimental for student achievement if they require a more active involvement of students in using ICT in the classroom.

Furthermore, the progressive inclusion of the rich set of controls available confirms the crucial role plaid by teacher's beliefs and attitude toward the use of ICT in influencing its actual effect on student performance.

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that these joint effect is very large, but it requires a simultaneous large increase in several ICT-teaching practices, making this case a sort of interesting theoretical benchmark.

[18] Notice also that most studies on class size reduction focus on elementary schools. Hence, this comparison should be taken as suggestive.

Overall, our results may help to explain why previous studies found little or no effects of ICT on learning, which may be justified by either the lack of detailed information on teachers' beliefs or by the use of a too crude measure for ICT practices.

Regarding the first issue, our estimates in Table 5 actually confirm that little effects are found only when teacher's beliefs are not controlled for, implying that they may act as confounding factors in the relationship between teaching practices and student performance. To our knowledge, this is the first evidence on the role plaid by teacher's beliefs emphasized in the educational literature.

Regarding the definition of ICT adoption, we claim that previous studies using a simple dummy on the availability of ICT in schools found little or no effect on students' achievement because of the heterogeneous effects of specific teaching practices linked to that ICT availability. The positive effect of some practices may be counterbalanced by the negative effect of others when an aggregate indicator of ICT in schools is used, thus leading to the wrong conclusion that ICT does not significantly affect student performance.

To test the sensitivity of our results to the definition of ICT, we use our data to compute more general measures of ICT and test their effects on our indicator of student achievement. Differently from most previous studies, in the Italian school setting we cannot use the availability of IWBs or PCs in classes, because both math and Italian language lessons are usually taken in the same classroom. Thus, we use alternative aggregates of the five factors or of the original 19 practices to measure the mere use of ICT by teachers in the two subjects, regardless of the specific teaching practices actually adopted. The main estimates of this exercise are reported in Table 6, where the columns differ only for the indicator of general use of ICT in the classroom that is considered. In column (1) to (5) we use, respectively, the standardized sum of the five factors, the number of practices employed among the original 19 ones (following Falck et al. 2015), the number of practices that are used intensively, a dummy equal to 1 if at least one of the original 19 practices is employed intensively, and a dummy equal to 1 if the teacher makes any use of ICT in the classroom (at least one hour a month). Regardless of the definition employed, as expected, the general use of ICT in the classroom has no statistically significant effect on student performance, and in most specifications (i.e., columns 1, 4 and 5), the estimated coefficient is close to zero.

In general, these results are in line with the educational literature mentioned above and confirm that the adoption of ICT *per se* is not necessarily beneficial for student learning, suggesting that student achievement will not benefit from simply increasing ICT availability and infrastructure indiscriminately.

TABLE 6 AROUND HERE

Finally, we estimate Equation [6] and test for the existence of heterogeneous effects of ICT teaching practices by subject. In Table 7, we report the coefficients of interest for our preferred specification. Our estimates show that ICT teaching practices enhancing communication and knowledge transmission significantly increase student performance only in the case of math, while their effect on Italian language is not statistically significant. On the contrary, the negative effect of practices requiring an active involvement of the students in the use of ICT is much larger and statistically significant in the case of Italian language. These results seem to suggest that the new technologies are more effective for student learning when they are employed to transmit concepts and knowledge in scientific subjects, while active use by students is particularly detrimental in the humanities, in which the contents and approach of the subject are more likely to favor an unproductive use of the Internet. Our results based on secondary education in Italy contribute to the ongoing international debate about subject specific teaching practices and their effects.

TABLE 7 AROUND HERE

6. Robustness checks

Previous results have been obtained using a within-student between-subject estimator, which allows us to fully control for unobserved heterogeneity at both the school and student level by obtaining differences between ICT-related teaching practices in math and Italian language. We controlled for teacher characteristics exploiting the richness of the survey that allowed us to control for a number of teacher variables, including proxies for teachers' innate ability, their motivation, their use of ICT and their beliefs about the use of ICT in schools. Despite this, we clearly cannot definitively rule out that there may be other unobserved factors that influence both the adoption of specific computer-based teaching methods and students' outcomes.

To test the robustness of our results to residual sources of endogeneity, we perform two robustness checks.

First, we test whether our main results are entirely driven by teachers who strongly believe in the usefulness of the new technologies in teaching and learning or by those who use intensely ICT and who perceive to be extremely skilled in the use of it. Exploiting the rich information available in our dataset on whether and how the teachers employ ICT in and outside the classroom, we create a dummy equal to 1 if the teacher is in favor of utilizing ICT for background activities, for teaching and for studying, and believes ICT has changed teaching in general and has had positive effects on her own teaching. We name this variable "Believer" because it identifies the teachers who deeply feel that the new technologies have changed or will change positively their way of teaching and education in general. We then create a second dummy, labeled "Heavy user", that takes a value of one if the teacher has a Facebook profile, uses a PC every day, surfs the net for more than one hour a day and has a relatively high subjective evaluation of her own ICT knowledge (higher than 6). With this variable, we want to capture whether teachers utilize ICT extensively and whether they are confident about their ability to use computers[19]. Compared to other teachers, as expected, both the "Believer" and the "Heavy user" are likely to use more frequently all of the five ICT teaching practices considered, except for the backstage activities in the case of the "Heavy users" (see Table A3 in the Appendix).

In Table 8, we report the main estimates obtained by interacting these dummies with the five factors measuring ICT teaching practices. In the first column, we report the interactions with the "Believer" dummy, and in the second one, with the "Heavy user" dummy. For each factor, the interaction effect should be interpreted as the differential effect for the "Believer" (column 1) and the "Heavy user" (column 2) with respect to other teachers. In both cases, the sign and significance of the intercepts' coefficients confirm our previous results. The interaction effects for the "Believer" are not statistically significant with the exception of media education, for which we find a lower effect with respect to the entire sample, and for communication-enhancing practices, for which we find a larger effect. Estimates in the second column show that compared with other teachers, the "Heavy users" obtain better results in terms of student achievement when they employ ICT for media education and for backstage activities, but when they use ICT for knowledge transmission in the classroom, the positive effect on student performance disappears.

Overall, estimates in Table 8 show that our main results discussed in the previous sections are not driven by subgroups of teachers who are particularly keen on – or familiar with – the use of ICT.

[19] Regarding the correlation between the two dummies and considering the total sample of 1736 observations, the "believers" constitute 17 per cent of total sample (295 observations), "heavy users" 12 per cent (208 observations). About 6 per cent of the total sample (107 observations) are both "believers" and "heavy users". Hence, albeit there is some overlapping between the two dummies, they actually identify different groups of teachers

TABLE 8 AROUND HERE

As a second robustness check, we replicate our estimates employing a different dataset, which allows us to use a within-teacher within-student estimator. We employ data from the 2011 Trends in International Math and Science Study (TIMMS) for 8th grade Italian students (who are two years younger than our students).[20] TIMSS data contain information on student achievement in math and science and detailed information on the corresponding teachers. Because in Italy, in the 8th grade, these subjects are taught by the same teacher, we reach identification exploiting the variation in the use of ICT-related teaching methods in different subjects taught by the same teacher to the same students.

The TIMSS survey contains two questions asking teachers information about the students' use of PCs in class. The first one covers primarily activities that require each student to have a computer and perform assignments such as looking up ideas and information or processing and analyzing data. The second one is related to the frequency of the use in class of specific software.[21] These questions refer to activities that are similar to those included in the teaching practice we have defined above as *active involvement* by students during lessons, for instance using general or specific software or explaining how to use websites to study or online encyclopedias.

To aggregate them, we built two dummy variables (one for math and one for science) taking the value of one when the teacher asks students to use a PC often (i.e "*daily or almost daily"* or "*once or twice a week"*) or when she uses software for teaching as a basic or supplementary resource. We observe a fairly significant variation in the use of these practices by subject. In general, active involvement practices are used only in one subject (either math or science) by 20% of teachers (see last row of Table A4 in Appendix).

We estimate a regression similar to the one specified in equation [5]. However, given that the same teacher teaches the two subjects, we can fully control for subject-invariant unobserved

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[20] TIMMS data are available for 34 countries. However, we use data only for Italy because we want to compare estimation results with those obtained using our dataset.

[21] The precise wording of the first question is as follows: *How frequently (daily or almost daily; once or twice a week; once or twice a month; never or almost never) do you ask your students to use a PC to do the following activities during math/science lessons? i. Practice skills and information; ii. Look up ideas and information; iii. Process and analyze data.* The second question is as follows: *When you teach math/science in this class, how do you use software for teaching math/science?* The possible answers are the following: *i. As a basic resource during lessons; ii. as a supplementary resource; iii. not used.*

teacher characteristics that influence both ICT-related teaching method adoption and students' performance exploiting within-student within-teacher variation (Metzler and Woessmann 2012).

In the preferred specification, we controll for several other subject-specific variables both at the teacher and at the student level. [22]

The results are displayed in Table 9. In columns (1) to (4), we consider one practice at a time, we add all of them in column (5) and, finally, we consider the aggregated dummy defined above, which is our preferred specification. Despite the different dataset, subjects and student grade, they confirm our previous results: in column (6), we see that ICT-related teaching practices requiring active involvement by students during lessons reduce their test score by 0.05 standard deviations and show to have a negative impact on student achievement.[23]

TABLE 9 AROUND HERE

Overall, estimates utilizing TIMSS data, where we can fully control for teacher subject-invariant characteristics, are in line with our previous results, suggesting that the rich set of controls for observable teacher characteristics and of proxies for their unobservable traits (e.g., motivation or innate ability in the use of ICT) allows us to properly control for unobserved teacher heterogeneity.

7. Conclusion

In this paper, we exploit a unique and rich student-teacher dataset to study the effect of a wide array of ICT-related teaching practices on student achievement. To control for different sources of unobserved heterogeneity, we employ a within-student between-subject estimator and

[22] Teacher-level variables are: weekly hours of teaching, self-evaluation of own ability to teach, no computer-based teaching methods (e.g., asking students to memorize facts, principles, rules or procedures or to relate the lesson to their daily lives), homework frequency and length and subject-specific training. Student subject-specific variables refer to self-evaluation of one's own performance and to attitudes toward the subject.

[23] With our data, when we use only ICT-related teaching practices requiring active involvement of the student, in the richest specification we obtain that an increase of one standard deviation of these practices reduce the test score by 0.17 standard deviations. However, the size of this effect is not directly comparable with that estimated with TIMMS data because of the different definition of teaching practices (a simple dummy in TIMMS data, a standardized factor in previous tables).

control for a large set of teacher ICT-related characteristics. Furthermore, in some specifications we allow for heterogeneous effects by subject.

Our main contribution to the existing literature consists in enlightening the relevance of teachers' practices in making ICT in classrooms effective or not for student achievement. Our analyses rely on a large number of specific practices considered and on the evaluation of the effect of different sets of practices separately.

The results confirm that ICT per se is not necessarily beneficial for student learning, as already shown by previous studies. In addition, we provide evidence on which ICT-related teaching methods matter for student achievement. More specifically, computer-based teaching practices increase student performance if they are aimed at increasing students' awareness of ICT use and at improving their navigation critical skills, developing students' ability to distinguish between relevant and irrelevant material and to access, locate, extract, evaluate and organize digital information. We also find a positive effect of ICT communication-enhancing practices, particularly in the case of math. In this case, the channel may be related to the enhancement of parental awareness of their children achievement or to an easier communication among teachers, favoring the sharing and mutual adoption of good practices. Instead, we find a negative effect of practices requiring an active role of students in class in utilizing ICT, particularly in the case of Italian language, probably due to the required investment of time and to the dramatic changes that they imply in classrooms .

Although our analysis is based on Italy, our results are likely to be confirmed in other contexts. Indeed, the Italian school system is similar to other countries as regards teachers' freedom in deciding on teaching practices: as a result of growing school autonomy and decentralization, in most European school systems – even in the most centralized countries, teachers are free to choose their teaching methods and materials (Eurydice, 2008).

Based on these results, policy makers should be anyway cautious regarding massive investments that focus on an active use of ICTs by students, especially if not accompanied by investment in teachers training. This does not mean, however, that policy makers should disinvest in this domain. Indeed, our results call for more investment in well-designed pilot interventions assessed through randomized controlled trials, in order to get accurate information about the conditions that render students' active use of ICTs beneficial.

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Table 1
Teacher and student characteristics by subject

VARIABLES	(1) Italian Mean (SD)	(2) Math Mean (SD)	(3) Difference (1)-(2) (SE)
Panel A: Teacher characteristics			
Male	0.237	0.134	.103***
	(0.426)	(0.340)	(.018)
Age	49.11	51.29	-2.17***
	(9.697)	(8.260)	(.432)
Phd	0.258	0.192	.065***
	(0.438)	(0.394)	(.020)
College final grade	108.4	98.10	10.25***
	(3.297)	(8.344)	(.304)
Permanent contract	0.775	0.917	-.141***
	(0.418)	(0.276)	(.017)
Weekly teaching hours	6.540	4.531	2.00***
	(1.979)	(1.728)	(.089)
Experience (years)	19.67	23.03	-3.361***
	(11.01)	(8.724)	(.477)
Tenure (years)	9.733	11.80	-2.07***
	(8.125)	(8.858)	(.408)
Motivation for teaching			
Responding to my need	0.123	0.0184	0.105***
	(0.329)	(0.135)	(0.0121)
Passion for the subject	0.333	0.470	-0.137***
	(0.472)	(0.499)	(0.0233)
Passion for teaching	0.278	0.252	0.0253
	(0.448)	(0.435)	(0.0212)
Willing to work among youth	0.160	0.104	0.0565***
	(0.367)	(0.305)	(0.0162)
Lack of other job opportunities	0.106	0.156	-0.0495***
	(0.308)	(0.363)	(0.0161)
Panel B: Student subject-specific variables			
INVALSI test score	78.055	58.24	19.81***
	(11.38)	(17.18)	(.699)
1st term grade	6.592	6.330	.262***
	(0.965)	(1.440)	(.058)
Familiarity with INVALSI-type tests	0.450	0.262	.189***
	(0.498)	(0.440)	(.022)
Subject important in life	0.505	0.889	-0.38***
	(0.500)	(0.314)	(0.020)
Subject important to learn other subjects	0.461	0.865	-0.40***
	(0.499)	(0.342)	(0.0205)
Subject important for future school career	0.457	0.652	-0.195***
	(0.498)	(0.477)	(0.0234)
Subject important for future work	0.472	0.781	-0.309***
	(0.500)	(0.414)	0.0220
Observations	868	868	1736

Table 2
Teacher ICT-related variables. Summary statistics by subject

Variable	Italian Mean (SD)	Math Mean (SD)	Difference (1)-(2) (SE)
ICT knowledge and training			
Number of correct answers in ICT test (from 1 to 15)	8.74	8.51	0.229**
	(0.080)	(0.083)	(0.11)
ICT subjective assessment (from 1 to 10)	6.029	6.438	-0.409***
	(1.511)	(1.686)	(0.0768)
ICT related training	0.364	0.551	-0.186***
	(0.481)	(0.498)	(0.023)
ICT use in spare time			
Number of hours on internet everyday	1.508	1.267	0.241***
	(0.902)	(0.866)	(0.042)
Use pc every day at home	0.926	0.895	0.0311**
	(0.261)	(0.307)	(0.014)
Have a facebook profile, Use pc every day at home	0.374	0.289	0.0853***
	(0.484)	(0.454)	(0.023)
ICT-related beliefs			
In favor of ICT use in preparing lecture	0.788	0.568	0.22***
	(0.409)	(0.496)	(0.021)
In favor of ICT use in teaching	0.643	0.615	0.027
	(0.479)	(0.487)	(0.023)
In favor of ICT use involving students	0.407	0.523	-0.116***
	(0.491)	(0.500)	(0.023)
Think ICT introduced important change in teaching	0.324	0.303	0.021
	(0.468)	(0.460)	(0.022)
Think ICT had very positive effect on her own teaching	0.0553	0.151	-0.095***
	(0.229)	(0.358)	(0.014)
Think my school is in favor of ICT adoption	0.495	0.669	-0.174***
	(0.500)	(0.471)	(0.0233)
Think my school is hostile to ICT adoption	0.136	0.0611	0.0749***
	(0.343)	(0.240)	(0.0142)
Think my colleagues are in favor of ICT use in our school	0.336	0.368	-0.0311
	(0.473)	(0.482)	(0.0229)
Think my colleagues are in favor of ICT use in our school	0.142	0.108	0.0334**
	(0.349)	(0.311)	(0.0159)
ICT use in teaching			
Number of hours using the interactive multimedia board	0.369	0.951	-0.581***
	(1.217)	(3.157)	(0.114)
Number of hours using a pc and projectors	1.586	0.942	0.644***
	(3.088)	(0.053)	(0.117)
Number of hours using a pc on their own during lessons	2.66	2.24	0.415
	(6.62)	(5.34)	0.288
Observations	868	868	1736

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Table 3
Principal components analysis - Rotated factor loadings (pattern matrix)

	Factor1 Knowledge transmission	Factor2 Media education	Factor3 Active involvement	Factor4 Backstage activities	Factor5 Communication	Uniqueness
Use slides during lessons	**0.8759**	0.0863	0.1143	0.0855	0.0571	0.2017
Use digital material during lessons	**0.8726**	0.0484	0.1765	0.0405	0.0681	0.1988
Show web-sites during lessons	**0.6916**	0.1885	0.2432	0.2018	0.0682	0.3817
Share files with students	**0.6475**	0.1225	0.2414	0.2469	0.1620	0.4202
Teach students about privacy on internet	0.1032	**0.8498**	0.0548	0.0049	0.0592	0.2607
Teach students how to use social media	0.0670	**0.8335**	0.1600	0.0247	0.0837	0.2676
Explain how to find studying groups in internet	0.2035	**0.6326**	0.1774	0.0633	0.1041	0.5121
Teach how to avoid viruses	0.0830	**0.5961**	**0.4559**	-0.0296	0.0653	0.4248
Teach how to evaluate the reliability of website content	0.0723	**0.5576**	**0.4899**	0.2032	-0.0625	0.3986
Use common software with students	0.2358	0.1702	**0.7846**	0.0611	0.1075	0.2845
Use specific software with students	0.2293	0.0607	**0.7810**	-0.0259	0.1842	0.2991
Explain how to study with internet	0.2585	0.2542	**0.6262**	0.2303	0.0585	0.4200
Teach students how to use online encyclopedias	0.1196	0.3761	**0.6062**	0.2486	-0.1373	0.3961
Prepare printouts	0.1828	0.078	0.1272	**0.7894**	0.0232	0.3206
Prepare test	0.0488	-0.0396	0.0632	**0.7098**	0.2684	0.4162
Use internet to prepare a lecture	**0.4127**	0.0703	0.0509	**0.5515**	0.0386	0.5165
Use pc to communicate with colleagues, students and their families	0.0836	0.0798	0.0795	0.1241	**0.7373**	0.4213
Exchange teaching material with colleagues	0.1608	0.1073	0.1524	0.1574	**0.6789**	0.4537
Attend online training course	0.3854	0.1673	0.095	-0.0274	**0.4383**	0.6215

Table 4

Teacher ICT-related practices. Summary statistics by subject

Variable	Italian Mean (SD)	Math Mean (SD)	Difference (1)-(2) (SE)
Factor 1: Knowledge transmission	-0.0713	0.0713	-0.143***
	(1.026)	(0.969)	(0.0479)
Factor 2: Media education	0.271	-0.271	0.542***
	(0.973)	(0.953)	(0.0462)
Factor 3: Active involvement	-0.210	0.210	-0.420***
	(0.844)	(1.096)	(0.0469)
Factor 4: Backstage activities	0.281	-0.281	0.561***
	(0.939)	(0.981)	(0.0461)
Factor5: Communication	-0.316	0.316	-0.632***
	(0.940)	(0.957)	(0.0456)
Observations	868	868	1736

Table 5
Effect of ICT-related teaching practices on student achievement
Within-student between-subject estimator

TEACHING PRACTICE	(1)	(2)	(3)	(4)	(5)	(6)
Knowledge transmission	0.0264	0.106	0.117	0.132	0.238	0.263**
	(0.0633)	(0.132)	(0.125)	(0.140)	(0.146)	(0.115)
Media education	-0.0325	0.0746	0.150*	0.172**	0.204***	0.199***
	(0.0467)	(0.0756)	(0.0802)	(0.0850)	(0.0752)	(0.0624)
Active involvement	-0.0627	-0.0446	-0.136*	-0.173*	-0.262**	-0.284***
	(0.0580)	(0.0807)	(0.0778)	(0.0897)	(0.105)	(0.0863)
Backstage activities	0.0863	0.0875	0.0283	0.0343	0.0697	0.0578
	(0.0596)	(0.0537)	(0.0627)	(0.0638)	(0.0663)	(0.0577)
Communication	0.130***	0.199**	0.224**	0.222**	0.287***	0.281***
	(0.0398)	(0.0950)	(0.0942)	(0.0852)	(0.0945)	(0.0763)
Teacher controls						
teacher characteristics	NO	YES	YES	YES	YES	YES
Teacher general beliefs	NO	NO	YES	YES	YES	YES
School perceived attitude	NO	NO	NO	YES	YES	YES
Teacher specific beliefs	NO	NO	NO	NO	YES	YES
Student subject-specific controls	NO	NO	NO	NO	NO	YES
Student fixed effect	YES	YES	YES	YES	YES	YES
Observations	1,736	1,736	1736	1736	1736	1736
R-squared	0.060	0.171	0.209	0.222	0.246	0.313
Number of ids	868	868	868	868	868	868
F-test ICT practices	3.805	1.362	2.245	3.281	3.936	5.551

Notes: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses (number of clusters: 47). All specifications include a constant and a subject dummy. Teacher controls are: male, age, PhD, college final grade, permanent contract, weekly teaching hours, experience, experience squared, tenure, tenure squared, motivation dummies, ICT critical knowledge test score, ICT subjective assessment, ICT related training, daily number of hours on the internet, a dummy for Facebook profile, a dummy for daily use of pc at home, ICT-related beliefs. Student subject-specific controls are: 1st term grade, familiarity with INVALSI-type tests and motivations to study each subject.

Table 6
Effect of general use of ICT on student achievement
Within-student between-subject estimator

VARIABLES	(1)	(2)	(3)	(4)	(5)
Standardized sum of factors	0.0148				
	(0.085)				
Sum of single practices		-0.0116			
		(0.0137)			
Number of intensively used practices			0.00254		
			(0.0308)		
At least one practice used intensively				0.431	
				(0.321)	
Use ICT in class for at least one hour in a month					-0.193
					(0.138)
Teacher controls	YES	YES	YES	YES	YES
Student subject-specific controls	YES	YES	YES	YES	YES
Observations	1,736	1,736	1,736	1,736	1,736
R-squared	0.253	0.256	0.253	0.259	0.258
Number of ids	868	868	868	868	868

Notes: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses (number of clusters: 47). All specifications include a constant and a subject dummy. Teacher controls are: male, age, PhD, college final grade, permanent contract, weekly teaching hours, experience, experience squared, tenure, tenure squared, motivation dummies, ICT critical knowledge test score, ICT subjective assessment, ICT related training, daily number of hours on the internet, a dummy for Facebook profile, a dummy for daily use of pc at home, ICT-related beliefs. Student subject-specific controls are: 1st term grade, familiarity with INVALSI-type tests and motivations to study each subject.

Table 7
Effect of ICT-related teaching practices on student achievement. Subject specific coefficients Within-student between-subjects estimator

VARIABLES	Coefficient	SE
Knowledge transmission_$_{\text{Italian language}}$	-0.102	(0.194)
Media education_$_{\text{Italian language}}$	-0.0581	(0.157)
Active involvement_$_{\text{Italian language}}$	-0.702***	(0.172)
Backstage activities_$_{\text{Italian language}}$	-0.054	(0.106)
Communication_$_{\text{Italian language}}$	0.220	(0.233)
Knowledge transmission$_{\text{_math}}$	0.404***	(0.125)
Media education$_{\text{_math}}$	0.0109	(0.144)
Active involvement$_{\text{_math}}$	-0.152	(0.115)
Backstage activities$_{\text{_math}}$	-0.0598	(0.099)
Communication$_{\text{_math}}$	0.331***	(0.086)
Teacher controls	YES	
Student subject-specific controls	YES	
Observations	1,736	
R-squared	0.335	
Number of ids	868	

Notes: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses (number of clusters: 47). All specifications include a constant and a subject dummy. Teacher controls are: male, age, PhD, college final grade, permanent contract, weekly teaching hours, experience, experience squared, tenure, tenure squared, motivation dummies, ICT critical knowledge test score, ICT subjective assessment, ICT related training, daily number of hours on the internet, a dummy for Facebook profile, a dummy for daily use of pc at home, ICT-related beliefs. Student subject-specific controls are: 1^{st} term grade, familiarity with INVALSI-type tests and motivations to study each subject.

Table 8
Heterogeneous effects by group of teachers
Within-student between-subject estimator

VARIABLES	(1)	(2)
Knowledge transmission	0.370***	0.225**
	(0.116)	(0.0899)
Media education	0.321***	0.214***
	(0.0856)	(0.0531)
Active involvement	-0.491***	-0.208*
	(0.153)	(0.115)
Backstage activities	0.169***	-0.0394
	(0.0607)	(0.0558)
Communication	0.434***	0.372***
	(0.0743)	(0.0641)
Knowledge transmission x believer	-0.117	
	(0.225)	
Media education x believer	-0.305***	
	(0.110)	
Active involvement x believer	-0.400	
	(0.267)	
Backstage activities x believer	-0.634	
	(0.546)	
Communication x believer	0.525**	
	(0.255)	
Knowledge transmission x heavy user		-0.598***
		(0.110)
Media education x heavy user		0.202**
		(0.0754)
Active involvement x heavy user		0.315*
		(0.174)
Backstage activities x heavy user		0.778***
		(0.189)
Communication x heavy user		0.115
		(0.207)
Teacher controls	YES	
Student subject-specific controls	YES	
Observations	1,736	1,736
R-squared	0.341	0.379
Number of ids	868	868

Notes: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses (number of clusters: 47). All specifications include a constant and a subject dummy. Teacher controls are: male, age, PhD, college final grade, permanent contract, weekly teaching hours, experience, experience squared, tenure, tenure squared, motivation dummies, ICT critical knowledge test score, ICT subjective assessment, ICT related training, daily number of hours on the internet, a dummy for Facebook profile, a dummy for daily use of pc at home, ICT-related beliefs. Student subject-specific controls are: 1st term grade, familiarity with INVALSI-type tests and motivations to study each subject.

Table 9
Effect of active student involvement - TIMMS data
Within-teacher within-student estimator

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Process and analyze data	-0.0715				-0.00901	
	(0.053)				(0.0558)	
Practice skills and information		-0.183***			-0.189***	
		(0.038)			(0.0560)	
Look up ideas and information			0.0156		0.0444	
			(0.0590)		(0.0423)	
Use software for teaching				-0.0652**	-0.0544*	
				(0.0311)	(0.0310)	
Active students involvement						-0.0567*
(dummy variable)						(0.0312)
Teacher subject-specific controls	YES	YES	YES	YES	YES	YES
Student subject-specific controls	YES	YES	YES	YES	YES	YES
Student fixed effect	YES	YES	YES	YES	YES	YES
Teacher fixed effect	YES	YES	YES	YES	YES	YES
Observations	6,878	6,878	6,878	6876	6,878	6,878
R-squared	0.083	0.085	0.083	0.086	0.086	0.082
Number of ids	3,439	3,439	3,439	3,439	3,439	3,439

Notes: *** p<0.01, ** p<0.05, * p<0.1. Clustered standard errors in parentheses (number of clusters: 176). All specifications include a constant and a subject dummy. Teacher subject-specific controls are: weekly hours of teaching, self-evaluation of own ability to teach, not computer-based teaching methods (e.g. ask students to memorize facts, principles, rules or procedures or to relate the lesson to their daily lives), homework frequency and length and subject-specific training. Student subject-specific controls are self-evaluation of own performance and attitudes towards the subject.

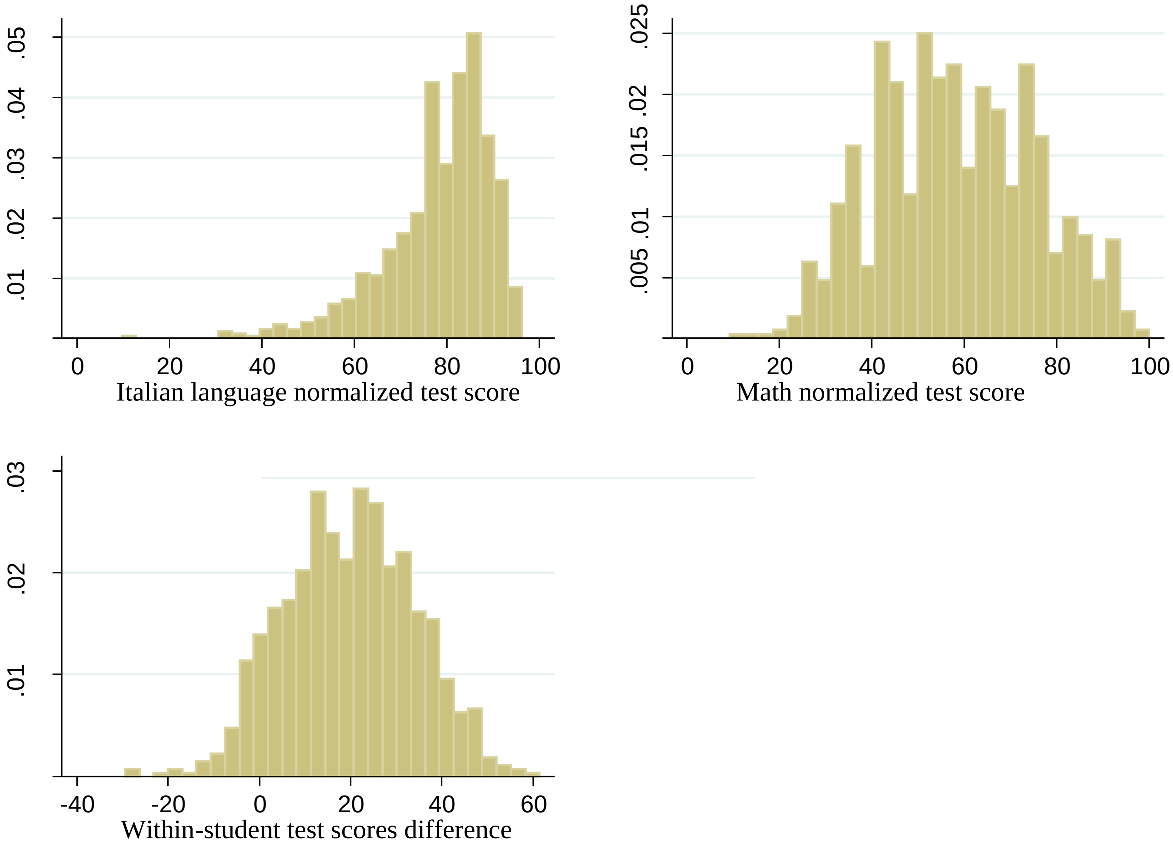

Figure 1

Italian language and math test score distributions and within-student difference.

Table A1
Use of ICT-related teaching practices. Summary statistics by subject
Row percentages

	Use slide			Use digital material			Share files with students			Prepare printouts			Preparing test		
	often	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*
Italian	16.36	35.02	48.62	15.78	29.84	54.38	15.55	52.19	32.26	43.78	56.22	0.00	54.61	45.39	0.00
Math	11.06	47.12	41.82	16.59	46.08	37.33	23.62	51.38	25.00	32.95	51.27	15.78	63.94	36.06	0.00
	Show web-sites during lessons			Use internet to prepare a lecture			Use pc to communicate with colleagues, students and families			Exchange teaching material with colleagues			Attend online training courses		
	often	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*
Italian	7.26	53	39.75	55.41	35.14	9.45	24.08	64.29	11.64	8.41	63.48	28.11	1.61	29.49	68.89
Math	15.21	40.9	43.89	49.42	41.47	9.1	42.17	49.65	8.18	16.71	61.18	22.12	2.53	37.21	60.25
	Teach students how to use online encyclopedias			Teach students how to use social media			Teach students about privacy			Use common software with students			Use specific software with students		
	often	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*
Italian	11.06	45.97	42.97	8.76	25.12	66.13	1.96	2.76	95.28	12.67	27.88	59.45	1.61	13.59	84.79
Math	9.22	21.43	69.35	2.53	19.93	77.53	0	4.49	95.51	31.45	37.1	31.45	17.74	29.38	52.88
	Explain how to study with internet			Explain how to find groups in internet			Teach how to avoid viruses			Teach how to evaluate the reliability of website content					
	often	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*	*often*	*sometime*	*never*			
Italian	18.09	55.76	26.15	0	13.25	86.75	0	4.49	95.51	8.87	52.19	38.94			
Math	17.05	38.25	44.7	2.07	4.49	93.43	2.53	8.29	89.17	2.53	39.75	57.52			

Table A2

Results from principal components analysis

Components	Eigenvalue	Difference	Proportion	Cumulative
Knowledge transmission	6.14959	3.98137	0.3237	0.3237
Media education	2.16822	0.90924	0.1141	0.4378
Active involvement	1.25898	0.09878	0.0663	0.504
Backstage activities	1.16021	0.11293	0.0611	0.5651
Communication	1.04728	0.15954	0.0551	0.6202

Note: All the factors are standardized with zero mean and standard deviation one.

Table A3

Use of ICT-related teaching practices by group of teachers. Factor means

TEACHING PRACTICE	Believer (SD)	Heavy Users (SD)
Knowledge transmission	1.14 (.60)	.69 (1.05)
Media education	0.92 (1.47)	.46 (1.56)
Active involvement	.66 (1.18)	.23 (1.22)
Backstage activities	.13 (.45)	-.08 (.79)
Communication	.28 (1.09)	.18 (1.10)
N. obs	295	208

Note: Each factor has been standardized, so the mean and the standard deviation on the whole sample are, respectively, 0 and 1.

Table A4
Use of active students' involvement ICT teaching practices. Summary statistics by subject. TIMMS data
Row percentages

	Math		Science	
	Often	*Sometimes or never*	*Often*	*Sometimes or never*
Process and analyze data	2.87	97.13	2.82	97.18
Practice skills and information	3.83	96.17	2.84	97.16
Look up ideas and information	4.76	95.24	6.22	93.8
	Basic or supplementary resource	*Not used*	*Basic or supplementary resource*	*Not used*
Use software for teaching	49.1	50.9	51.01	48.99
	YES	*NO*	*YES*	*NO*
Active student involvement dummy	50.33	49.67	52.20	47.80

Active student involvement used	**Only in Math**	**Only in Science**	**Both**	**Neither**
	8.94	11.61	40.71	38.74