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How the ICT development level and usage influence student achievement in reading, mathematics, and science

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ABSTRACT

The main purpose of this study is to investigate how national ICT development level and individual ICT usage will influence achievements in reading, mathematics, and science for 4th and 8th grade school students. Large-scale international databases, including TIMSS 2011, PIRLS 2011, and PISA 2012, were employed in the current study. Hierarchical linear models (HLM) were applied to examine both country- and individual-level variables. According to the findings of this study, the national ICT development level is a significant positive predictor for individual academic performance in all three subjects for both 4th grade and 8th grade students, while the national economic development level was controlled for. Such finding indicates a similar trend of the ICT influences for both groups, although there exists a difference in terms of the extent of the relationships. In addition, individual-level ICT use is a significant predictor, even if students' gender and socioeconomic status are controlled for; however, its influence is mixed across different student groups and subjects depending on the ICT usage type.

controlled for???

1. Introduction

In the context of information societies, ICT has been perceived as one of the most important tools in changing education, based on the contemporary information society needs (Blackwell, Lauricella, & Wartella, 2014; U.S. Department of Education, 2010). Therefore, many countries have implemented ICT-related policies and invested considerable resources in ICT infrastructures in schools (Witte & Rogge, 2014). The integration of ICT in teaching and learning is aimed at improving students' 'twenty-first century skills' (Anderson, 2008; Kim, Kil, & Shin, 2014) and achieving major international goals such as EFA (Education for ALL) and the WSIS goals (World Summit of Information Society) (WSIS, 2003). Moreover, the application of ICT in education might be helpful for increasing opportunities for learning and reducing the gap between socioeconomic factors and education system outcomes (Shank & Cotton, 2014). It is also believed that integrating ICT with education would create talented teacher communities where professionals can share their best practices and success stories and thus improve the quality of education (Cox, 2008).

However, the planned application of ICT in education is determined to a large extent by national ICT development, in that national ICT policies and plans provide the principle means for ICT to contribute significantly to a society's sustainable development (FAIDP, 2010). Moreover, national ICT development can also be a driver for educational reforms through the introduction of new teaching and learning practices, facilitating the restructuring of the education system (Kozma, 2002). Although the importance of a highly developed national ICT level for overall education quality has been recognized by governments, few studies have addressed whether the national ICT level will influence student learning outcomes. As a review of the literature shows, a large number of studies focused on the impact of ICT on students' achievements and individual skills (Carrasco & Torrecilla, 2012; McMahon, Yeo, & Williams, 2011). However, most of these studies investigated the usages of ICT in the classroom or at home, rather than considering ICT as an environmental factor at the national level. This study draws on large-scale data, combining survey responses from students with rich administrative data from international authorities to identify whether the national ICT level and individual ICT usage matter for student learning outcomes. The purpose of this research is to

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present evidence about the relationship of both ICT development (national level) and ICT usage (individual level) with achievement in reading, mathematics, and science for 4th and 8th grade students by exploring three international large-scale student assessment projects: the Trends in International Mathematics and Science Study (TIMSS 2011), the Progress in International Reading Literacy Study (PIRLS 2011), and the Programme for International Student Assessment (PISA 2012).

2. Background

2.1. The National ICT Level and Education Development

Information and communication technologies (ICT) are defined as a “diverse set of technological tools and resources used to communicate and to create, disseminate, store, and manage information” (Blurton, 1999). A broad definition of ICT includes computers, the Internet, telephones, personal digital assistants (PDAs) and mobile phones, television, radio and audio-visual equipment. Taking into account the importance of ICT for social development, several initiatives exist for measuring and monitoring ICT level (IADB, 2010; ITU, 2010; UIS, 2009). The International Telecommunication Union (ITU) is the United Nations' specialised agency for information and communication technologies. In 2006, the ITU was asked to develop a single index, called the ICT Development Index (IDI), to measure the extent of a country's ICT level (ITU, 2010). The overall national ICT level has the inherent power of promoting the modernisation of society, including the education system.

As more and more educators and policymakers have begun to value the potential benefits of ICT in the revolution of the modern education system, more and more advanced ICT equipment has been introduced and invested into schools and classrooms. In 2009, the UNESCO Institute for Statistics (UIS) introduced a three-level model of ICT integration in education (UIS, 2009). It consists of three levels (see Fig. 1):

1) **Readiness.** The readiness of the infrastructure, society, and the education system to undertake ICT activities in the education system. The main criteria are access to and use of basic ICT infrastructure, ICT-trained teachers, ICT support staff, radio and television instruction, educational software, email and other “simple” educational technologies.
2) **Intensity.** The intensity of the use of ICT and the extent to which ICT activities in education (such as distance education and mobile learning) are carried out by the government and business. The main criteria are ICT-enhanced content development and innovative pedagogy management, new ICT vocational skills development, the expansion of ICT-related fields of studies, distance education, virtual and open universities, virtual high schools, virtual laboratories and online simulations, digital libraries, and Internet-enabled self-learning.
3) **Impact.** The outcomes and impacts of ICT on business activities and economic growth in countries with a relatively high level of ICT in education. The main criteria are the availability of ICT for lifelong learning, ICT and student achievements, tracer studies on ICT-skilled students in the labour market, the relationship between ICT in education and economic productivity, webcasting, podcasting, and videoconferencing.

According to the three-level model, the development of the overall national ICT level will help in achieving not only national developmental goals but also major international goals set by the WSIS (WSIS Plan of Action, WSIS, 2003), MDGs (Millennium Development Goals), and the EFA (Education for All), which are related to the use of ICT in education for expanding teaching and learning opportunities, for improving educational achievements, for promoting educational reformation, for achieving education equality and equity (Kozma, 2002;

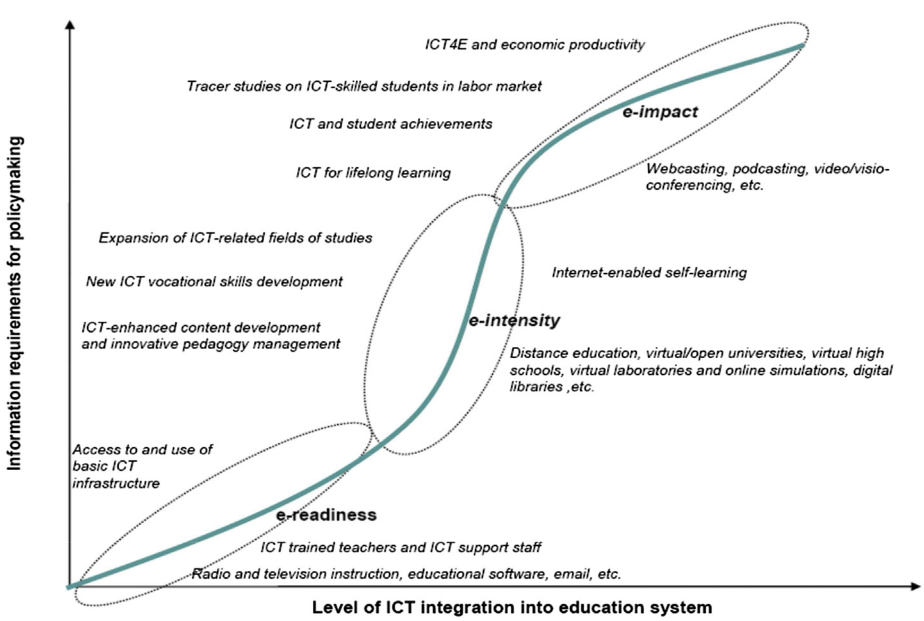

Fig. 1. Information needs for different types of ICT in education over time.
Source: UIS (2009).

SNA, 2004; Zemsky & Massy, 2004), for increasing learners' employability and diversity of life skills, and for integrating education with private partnerships (UIS, 2009). Thus, the development of ICT has been placed as an important strategy for improving the overall national economy (Luu & Freeman, 2011).

2.2. ICT use and its influences on student achievement

In the area of education, a growing body of evidence demonstrates that ICT is an effective means for addressing educational needs, goals and requirements (Gumus & Atalmis, 2011). Therefore, the effects of ICT use on students' development have gained more and more attention from both education policy makers and researchers (Aypay, 2010; Gumus & Atalmis, 2011; Luu & Freeman, 2011; Ponzo, 2010). Meanwhile, many empirical studies of the influences of ICT on student learning outcomes have been conducted (McMahon et al., 2011). Prior research on this topic can be categorized into two broad categories. The first category of studies primarily addressed the effectiveness or efficiency of ICT application on student academic performance by comparing innovative ICT-based instruction with traditional instruction. The second category of studies aimed to find the relationship between ICT use and student learning outcomes using cross-sectional data, especially large-scale survey data.

Regarding the first category of studies, focussing on effectiveness, a number of meta-analysis reviews indicated positive but small to moderate impacts (Bayraktar, 2002; Kulik, Bangert, & Williams, 1983; Kulik & Kulik, 1991; Torgerson & Zhu, 2003). In 1983, Kulik and his colleagues compared and evaluated 51 studies on computer-based teaching in grades 6–12 using meta-analysis methods and discovered that computer-based teaching would be helpful in increasing students' scores on final examinations, but with a small effect size equal to approximately 0.32 (Kulik et al., 1983). With the aim to follow up on the trend, Kulik conducted an updated review of the effectiveness of computer-based instruction again (Kulik & Kulik, 1991). The sample of studies was enlarged to 254, and the average effect size was found to be 0.30, which confirmed Kulik's earlier findings. Similarly, Bayraktar conducted another meta-analysis of 42 studies (between 1970 and 1999) to compare computer-assisted instruction to traditional instruction and revealed that the computer-assisted teaching environment outperformed the tradition one generally, with the effect size from −0.69 to 1.30 and an average of 0.27 (Bayraktar, 2002). Torgerson and Zhu (2003) reported mixed evidence in their systematic literature review on the effectiveness of ICT in literacy learning (ages 5–16 years): they made 20 comparisons among 12 research papers and found 13 positive (four were statistically significant) and seven negative (only one was significant) effect sizes. According to these reviews, the effect of ICT usage on student performances can be positive but is usually small to moderate. In addition to these synthesized reviews, a few recent small-scale studies related to using ICT in the classroom and at home have produced contradictory findings. Valentine et al. reported a statistically significant improvement in English and mathematics achievement related to the use of ICT at home (Valentine, Marsh, & Pattie, 2005). Banerjee et al. found that a computer-assisted learning programme for mathematical skills reinforcement showed a large and positive impact on achievement in mathematics as well (Banerjee, Cole, Duflo, & Linden, 2004). Nevertheless, some researchers reported that there was a lack of evaluations about ICT practices in schools and little evidence about the impact of ICT on learning outcomes (Blackmore, Hardcastle, Bamblett, & Owens, 2003). For example, when comparing online learning with face-to-face learning, student performances were usually lower (Anstine & Skidmore, 2005; Coates, Humphreys, Kane, & Vachris, 2004). Coates et al. compared student performance in two different economic learning environments, online learning and face-to-face learning, and found that students in online courses achieved 15% lower scores compared to their peers in the face-to-face course (Coates et al., 2004). Anstine and Skidmore also reported similar findings for a statistics course (Anstine & Skidmore, 2005).

The second category of studies in this research field attempts to look for a relationship between ICT usage and student achievement. Such a topic has been explored using different national large-scale surveys. In the United Kingdom, ImpaCT2 was one of the most comprehensive large-scale studies about the impact of ICT on achievement (Harrison et al., 2001). Evidence from the study showed mixed results in terms of the influences of ICT on student achievement in English: a statistically significant impact for ICT was found on the group of five-year students, but not for eight- or ten-year students. However, it was reported that ICT had a positive relationship with student achievement in mathematics (Harrison et al., 2002). Carrasco and Torrecilla investigated how computer access and use influence the performance of Latin American primary students in 6th grade. Using four- and three-level models, they found that student performance in reading and math increased significantly if they students had a computer in their home, whereas overall school performance increased even more if there were more than ten computers at school (Carrasco & Torrecilla, 2012).

In recent years, the amount of research in this area has increased as the interest in ICT usage measurement in international large-scale assessments has grown. Since 2000, PISA has run an additional survey to map the use of ICT, including questions about access to various ICT technical devices and tools, the frequency of use, and self-efficacy in using ICT. It became one of the most commonly used data sources for investigating this question. However, the findings were still mixed. Based on the PISA 2003 results, it was discovered that regular computer users have higher achievement in key school subjects (OECD, 2006). Similarly, based on the PISA 2009 results, Delen and Bulut indicated that students' familiarity with ICT and their exposure to technology could contribute to explaining math and science achievement gaps between individuals and schools (Delen & Bulut, 2011). Moreover, Lee and Wu reported that according to the PISA 2009 results, student reading literacy improved if students had better attitudes and higher confidence toward computers and if ICT equipment was available at home. However, such a relationship was mediated by their engagement in online reading (Lee & Wu, 2012). Fuchs and Woessmann used data from the PISA 2000 and found a significantly positive relationship between reading achievement and the availability of computers both at home and at schools; however, this relationship turned out to be negative or insignificant when the social economic background of students' families and school characteristics were controlled for (Fuchs & Woessmann, 2004).

2.3. Rationale for the current study

Based on the review of previous studies, we are able to gather a more comprehensive understanding of the influences of ICT. Overall, a rich body of research concerning the effectiveness of ICT has indicated small to moderate positive impacts on student learning outcomes, whereas studies on the relationship between ICT use and student performance have reported more mixed findings. Several important trends discovered in the literature review are worth pointing out and might contribute to the inconsistency. First, in past decades, a shift in the meaning of the “integration of ICT in education” has taken place, from the preliminary introduction of a television in the classroom to the provision of Internet access for online teaching and learning (Blackwell et al., 2014). Similarly, regarding ICT usage, the diversity of available applications and tasks have expanded dramatically as well, from simple "Word" or "Excel" processing skills to more advanced ICT-related skills. Due to these changes, the term "influence of ICT" across different studies did not have the same meaning, which might explain the discrepancy of results. Second, the notion of a "learning outcome" encompasses a variety of different aspects of students (Garcia, Nussbaum, & Preiss, 2011), including their psychological attributes, such as attitudes or engagement, and their achievements. Although research has shown that ICT usage would enhance students' motivation and engagement in learning (Becta, 2003; Passey, 2005; Passey, Rogers, Machell, & McHugh, 2004; Pittard, Bannister, & Dunn, 2003), the relationship between ICT usage and student achievement is still inconsistent. Third, ICT usage as explored in previous studies primarily focused on school-level integration or individual student use, overlooking the influence of national ICT development level on student academic achievements. The current study aimed to fill this gap in prior research by including both the national ICT level and individual ICT usage in the same model, while controlling similar variables. By employing large-scale international student assessment data including different nations with diverse levels of ICT development, the trends in the influences brought by the national ICT level to individual student performances can be investigated.

3. Methodology

3.1. Data sources

The data sources for this research include the TIMSS 2011, PIRLS 2011, PISA 2012, International Telecommunication Union, and World Bank datasets. After excluding missing data and data cleaning, the final sample contained 43 countries and 241,577 cases in the PIRLS 2011 dataset, 38 countries and 200,650 cases in the TIMSS 2011 dataset, and 39 countries and 283,153 cases in the PISA 2012 dataset.

TIMSS 2011 & PIRLS 2011. The Trends in International Mathematics and Science Study (TIMSS) is an international study of mathematics and science achievement in 4th and 8th grade students. The Progress in International Reading Literacy Study (PIRLS) is an international study of reading achievement among 4th grade and 8th grade students. Both of these studies were conducted by the International Association for the Evaluation of Educational Achievement (IEA). The TIMSS 2011 and PIRLS 2011 databases were analysed with the purpose of investigating whether the national ICT development level and individual ICT use influence 4th grade school students' literacy in math, science, and reading.

PISA 2012. The Program for International Student Assessment (PISA) is an international study that measures 15-year-old students' reading, mathematics, and science literacy. It is conducted by the Organization for Economic Cooperation and Development (OECD). The PISA 2012 dataset was used to explore whether the proposed influences exist for secondary school students.

International Telecommunication Union. The International Telecommunication Union (ITU) is a special agency governed by the United Nations. It holds responsibility for all issues related with information and communication technologies, including coordinating the shared global use of the radio spectrum, promoting international collaborations in assigning satellite orbits, facilitating telecommunication infrastructure in the developing countries, and assisting in developing worldwide technical standards. The ITU developed the ICT Development Index (IDI), which is based on 11 ICT indicators.

3.2. Data analysis

3.2.1. Variables

This study used country- and individual-level variables. Country-level variables include the ICT level, ICT rate of change, and logarithm of GDP per capita. Individual-level variables include reading/mathematics/science scores, the index of ICT use, gender, and socioeconomic status (SES).

National ICT level. The ICT Development Index (IDI) in 2011 is used to indicate the national ICT level. It is based on 11 ICT indicators that are grouped into three clusters: access, use and skills. The first cluster (access) includes five infrastructure and access indicators: fixed-telephones, mobile-cellular telephones, international Internet bandwidth, households with computers, and households with Internet access. The second cluster (use) includes three ICT intensity and usage indicators: Internet users, fixed (wired)-broadband, and wireless broadband. In the absence of data on ICT skills, the third cluster (skills) includes three proxy indicators based on the International Telecommunication Union dataset: adult literacy, gross secondary enrolment and gross tertiary enrolment (ITU, 2012).

ICT rate of change. The ICT rate of change is calculated with the values from the ICT Development Index in 2007 and 2011.

$$ICTRoC = \frac{IDI2011 - IDI2007}{IDI2007}$$

The logarithm of GDP per capita. GDP per capita and its logarithm were obtained from the World Bank dataset. It is often considered an indicator of a country's standard of living, which is also regarded as an important factor of student achievement. Therefore, the LnGDPs were included in the models as the controlling variables.

Reading/mathematics/science score. Individual scores from the TIMSS 2011, PIRLS 2011, and PISA 2012 surveys were obtained for reading, mathematics, and science, respectively. The international surveys used a rotated-booklet design for testing individual literacy and numeracy skills. This means that each participant completed only a small part of the whole set of test items. However, researchers are interested in giving a score to each student that is comparable across all students. Five plausible values (PV scores) are a representation of the range of abilities that a participant might reasonably achieve if she/he had completed the whole test, taking into account the measurement error in the test (Willms & Smith, 2005). In other words, the logic behind the plausible values consists of "mathematically computing distributions (denoted as posterior distributions) around the reported values and the reported length in the example; and assigning to each observation a set of random values drawn from the posterior distributions" (OECD 2009, p. 95).

In all three international assessment programs, systematic probability proportional-to-size (PPS) sampling techniques were employed, which was a natural match with the hierarchical nature of the clustered sampling units. Due to the multistage cluster sampling, the Balanced Repeated Replication (BRR) technique with 80 replicates was employed for estimating sampling error in the PISA data, whereas the Jackknife technique with 75 replicates was used for the TIMSS and PIRLS data. The models were analysed using SAS software.

The ICT use. In the present study, "ICT use" specifically refers to the "frequency of ICT use at school or home with different purposes". The PISA 2012 ICT questionnaire contains ten questions about ICT entertainment use (ENTUSE), seven questions about ICT use at home for school-related tasks (HOMSCH), and nine questions about ICT use at school (USESCH). All three indexes were included in the analysis. The TIMSS 2011 and PIRLS 2011 background questionnaires contain questions about the frequency of ICT use at school and home, both of which were included.

Student background information. Two variables indicating student background, social economic status (SES) and student gender, were used as the controlling variables in the model. For the TIMSS 2011 and PIRLS 2011 data, SES was calculated as the mean of home possession of a computer, study desk, books, private room, Internet connection, and up to six country-specific home possessions. A negative scale was used because the answer "1" means "yes" and the answer "2" means "no". For the PISA 2012 data, the value of the index of economic, social and cultural status (ESCS index) was used.

3.2.2. Hierarchical linear modelling

In the present study, hierarchical linear modelling (HLM) was used to model the individual- and country-level variables. HLM has been widely used to predict a dependent variable on the condition of using multiple independent variables coming from different levels and to examine the dynamics between micro- and macro-levels (Raudenbush & Bryk, 2002), given its advantages in dealing with the problems in traditional regression analysis, such as aggregation bias and under-estimated standard errors (Lee, 2000). Because in all three international assessments, the sampled units (students) are nested within larger units (countries), HLMs were employed to analyse both the individual- and country-level variables and to explain the variation in student outcome scores while accounting for the variance at each level (Hox, 2000). All of the models have the same structure for reading, mathematics, and science as well as for both 4th and 8th grade students.

The analyses began with null models that were created to determine the extent to which observations within countries are correlated. This simplest analysis involves the use of one-way ANOVA with random effects (Raudenbush & Bryk, 2002). The null model is used to partition the variance in the dependent variable (e.g., reading scores) into within- and between-group components (Willms & Smith, 2005), justifying the use of hierarchical modelling analysis. The intraclass correlation coefficient (ICC), an indicator of the size of the clustering effect, was calculated to estimate the degree to which between-country variances were represented in the total variation of the student scores. The second step is to include all of the predicting variables from student level (ICT use, student gender, and student SES) in the models. The last analysis step is to include the core predictors from country-level data in the models established in the second step, with the aim of estimating the effect of these predictors. The final two-level HLM model is as follows:

$$Score_{ij} = \beta_{0j} + \beta_{1j}*SES_{ij} + \beta_{2j}*Gender_{ij} + \beta_{3j}ICTUSE_{ij} + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}ICTLEVEL_j + \gamma_{02}ICTRoC_j + \gamma_{03}\ln GDP_j + u_{0j}$$

$$\beta_{1j} = \gamma_{1j}$$

$$\beta_{2j} = \gamma_{2j}$$

$$\beta_{3j} = \gamma_{3j}$$

where

$SCORE_{ij}$ is the reading/mathematics/science scores for the individual i in country j,
γ_{00} is the mean reading/mathematics/science scores for all of the countries in the sample,
γ_{1j} is the slope of SES for individual in country j,
γ_{2j} is the slope of gender for individual in country j,
γ_{3j} is the slope of ICT use for individual in country j,
r_{ij} is a unique error associated with the individual i in country j,
γ_{01} is the slope of ICT level for each country,
γ_{02} is the slope of ICT rate of change for each country,
γ_{03} is the slope of lnGDP for each country, and
u_{0j} is a unique error to the intercept associated with country j and has the variance τ_{00}.

4. Results

4.1. Null models

For all six null models, the calculation of the percentage of each variation source delivers the proportion of the variance that is attributed to differences between countries. It turned out that for 4th grade students, 30%–40% of the variability in each model could be attributed to the countries (between country variance). For 8th grade students, the percentage of variability attributed to the countries was between 10% and 20% (Table 1). Thus, further analyses with HLMs are necessary to explore the impacts of predictors from different levels.

4.2. Random intercept model with controlling variables from both levels (model 1)

During the second stage of the analysis, the controlling variables from student (individual) level and country level were integrated into the model (See Tables 2 and 3), with the aim of identifying the effectiveness of the target predicting variables. The two individual demographic variables, namely SES and gender, and national GDP were included.

Table 1
Intraclass coefficient for null models.

	Primary 4th grade			Secondary 8th grade		
	Reading	Mathematics	Science	Reading	Mathematics	Science
Country-level effect (u_{0j})	3214.58	3225.14	3879.35	1082.9	1714.76	1354.11
Individual-level effect (r_{ij})	5284.06	6076.51	6631.64	7831.9	7809.44	7275.95
ICC	38%	35%	37%	12%	18%	16%

Across all three subjects and two grades, student SES was found to have consistently positive influences on student achievements; thus, students who have higher SES levels tend to have better achievements. Regarding the gender difference in all three subjects, it was discovered that for both grades, the gender gap is far wider in reading than it is in either mathematics or science. The gaps were significant but with different directions: girls outperformed boys in reading, whereas boys outperformed girls in both mathematics and science. Such trends were observed in both the 4th grade group and 8th grade group. In addition, national GDP level was also found to show significant positive influence on achievements for 4th and 8th grade students.

Comparing Model 1 and null model across all of the datasets, it can be concluded that students' demographic information and national trait can contribute to explaining the additional variations in student achievement. Overall, in Model 1 with the combined controlling variables, the reduced variation was about 30%–40% at the country level and approximately 10%–15% at the student individual level on average.

4.3. Random intercept full model with target predictors from both levels (model 2)

In the third stage (Model 2), two target variables measuring the national ICT development level and rate were included in the model, so were the variables indicating the individual ICT usage. For both the TIMSS and PIRLS datasets, two variables measuring the frequency of student ICT usage at home and at school were examined. For the PISA data, three variables measuring the frequency of student usage at school, at home for school-related purposes, and for entertainment purposes were integrated into the model. Tables 4 and 5 present the output of the six full models for 4th and 8th grade students' achievements in reading, mathematics, and science. It was found that the effects of the national ICT development level on individual achievement in reading, mathematics, and science were all consistently positive, with the national GDP controlled for. This positive effect indicated that individuals who are in countries with higher ICT levels have higher achievement in all subjects. Specifically, the average score increment of three subjects related with one unit change of the national ICT level was 38.32, 39.12, and 43.02 for 4th grade students; while was 12.68, 21.61, and 19.14 for 8th grade students. It was known the achievement scores in all three international surveys had normally distributed IRT scores with mean of 500 and a standard deviation of 100. Thus, every unit increase in national ICT level might relate with about 0.4 stand deviation attainment for 4th grade students, while about 0.2 standard deviation attainment for 8th grade students. In conclusion, the influences of national ICT level on students in both grades showed similar positive pattern, but differed in terms of the extent.

The ICT rate of change, which indicates the national trend of ICT development over the past five years, had a negative relationship with student achievement. However, all of these relationships were found to be non-significant with the only exception being 4th grade students in reading. Thus, in general, it was found that the increasing rate did not have a consistently significant impact on student achievement.

In terms of student ICT usage on the individual level, the results from the TIMSS and PIRLS datasets showed a consistent trend indicating significant and positive influences of both ICT use at home and at school on 4th grade students' achievements in reading, mathematics, and science, even while controlling for student SES and gender. However, for the 8th grade students, the findings obtained from the PISA data were slightly complex. It was revealed that students' ICT usage at school showed negative influences on student achievement in all three subjects. In contrast, if students spend more time using ICT for school-related tasks at home, they are more likely to achieve more than others who spend less time. Moreover, students' use of ICT for entertainment purposes also showed significantly positive effects on their achievements in reading and math but not for science.

Compared with Model 1 in the second stage, a combination of all of the variables in Model 2 at the country level accounted for approximately 60% of the variance at the country level and up to 17% at individual level. National ICT development level would explain up to 20% of the additional variation of student achievements at the country level.

5. Discussion

By presenting a multilevel model including both the national ICT development level and students' individual ICT usage, this study sheds light on the complex influences of ICT on student achievements in reading, mathematics, and science. First, this study adds to the literature

Table 2
The random intercept model with controlling variables only for primary students' literacy in reading, mathematics, and science.

	Reading literacy (PIRLS)		Mathematics literacy (TIMSS)		Science literacy (TIMSS)	
Fixed effects	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**
Intercept (γ_{00})	215.43 (190.31)***	1.13	171.16 (117.11)***	1.46	162.00 (109.00)***	1.49
SES (β_{1j})	86.86 (83.40)***	1.04	81.49 (111.33)***	0.73	95.78 (145.13)***	0.66
Gender	−14.53 (−76.88)***	0.19	5.11 (31.03)***	0.16	3.62 (20.98)***	0.17
ln GDP (γ_{03})	23.86 (3.20)***	7.45	26.21 (3.10)***	8.45	29.98 (2.74)**	9.47
Random effects	**Variance**	**S.E.**	**Variance**	**S.E.**	**Variance**	**S.E.**
Country-level effect (u_{0j})	2018.71 (208.63)	9.72	2175.04 (191.31)***	11.37	2732.37 (179.14)***	15.25
Individual-level effect (r_{ij})	4657.30 (75.82)	61.43	5283.80 (74.62)***	70.81	5663.71 (75.05)***	75.46
% of reduced Variance of u_{0j}	37.20%		32.56%		29.57%	
% of reduced Variance of r_{ij}	11.86%		13.04%		14.59%	

*: p<0.05, **: p<0.01, ***: p< 0.001.

Table 3
The random intercept model with controlling variables only for secondary students' literacy in reading, mathematics, and science.

	Reading literacy (PISA)		Mathematics literacy (PISA)		Science literacy (PISA)	
Fixed effects	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**
Intercept (γ_{00})	306.01 (45.79)***	6.68	216.89 (31.42)***	6.90	278.46 (43.25)***	6.44
SES (β_{1j})	31.08 (51.65)***	0.60	31.86 (52.84)***	0.60	29.53 (50.68)***	0.58
Gender	−34.44 (−38.13)***	0.90	11.28 (12.63)***	0.89	1.21 (1.42)***	0.85
ln GDP (γ_{03})	20.67 (3.67)***	5.64	27.01 (3.84)***	7.04	21.93 (3.46)***	6.34
Random effects	**Variance**	**S.E.**	**Variance**	**S.E.**	**Variance**	**S.E.**
Country-level effect (u_{0j})	650.65 (27.95)***	23.28	1021.04 (35.31)***	28.92	820.50 (34.29)***	23.93
Individual-level effect (r_{ij})	6702.33 (101.41)***	66.09	6887.65 (96.98)***	71.02	6508.67 (99.40)***	65.48
% of reduced Variance of u_{0j}	39.92%		40.46%		39.41%	
% of reduced Variance of r_{ij}	14.23%		11.80%		10.54%	

*: p<0.05, **: p<0.01, ***: p< 0.001.

Table 4
The random intercept full model for primary students' literacy in reading, mathematics, and science.

	Reading literacy (PIRLS)		Mathematics literacy (TIMSS)		Science literacy (TIMSS)	
Fixed effects	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**
Intercept	551.96 (6. 92)***	79.81	474.13 (5.49)***	86.29	495.27 (5.14)***	96.37
SES	95.15 (120.57)***	0.79	85.58 (84.36)***	1.01	103.27 (98.64)***	1.05
Gender	−13.62 (−47.63)***	0.29	6.55 (19.52)***	0.34	5.08 (14.67)***	0.35
Home use	4.06 (27.75)***	0.17	3.27 (18.00)***	0.18	4.89 (26.12)***	0.19
School use	6.28 (42.09)***	0.15	5.32 (29.50)***	0.18	6.76 (36.32)***	0.19
ICT level	38.32 (5.43)***	7.06	39.12 (5.11)***	7.65	43.02 (5.03)***	8.55
ICT rate of change	−73.26 (−2.02)*	36. 28	−51.58 (−1.31)	39.32	−67.34 (−1.53)	43.92
ln GDP (γ_{03})	−34.65 (−3.19)**	10.87	−29.23 (−2.52)**	11.60	−35.47 (−2.74)**	12.95
Random effects	**Variance**		**Variance**		**Variance**	
Country-level effect (u_{0j})	989.52		1111.05		1387.51	
Individual-level effect (r_{ij})	4533.47		5293.66		5673.73	
% of reduced Variance of u_{0j}	69.22%		65.56%		64.23%	
% of reduced Variance of r_{ij}	14.24%		12.97%		14.45%	

*: p<0.05, **: p<0.01, ***: p< 0.001.

by exploring the impact of the national ICT development level on student achievements, which has been ignored in previous studies. Such findings would be very helpful for better understanding how national ICT development and its related policies will influence individual student learning outcomes. Second, by employing a new way of examining the three widely recognised large-scale international student assessments, this study encompasses a broad spectrum of participants worldwide. Moreover, it is remarkable that consistent trends have been indicated across all three subjects and both grade levels. As a result, the findings are of particular importance for both education researchers and policy makers.

5.1. The influence of national ICT indicators on student achievement

Two country-level predictors of ICT development were considered in this research: ICT level and ICT rate of change. The effects of the national ICT development level on individual achievements in reading, mathematics, and science were positive, even though the national economic level index was controlled for. The positive effect of the ICT level on individual achievements means that individuals who are in countries with higher ICT levels are more likely to have higher achievement. The difference in student achievement caused by the national

Table 5
The random intercept full model for secondary students' literacy in reading, mathematics, and science.

	Reading literacy (PISA)		Mathematics literacy (PISA)		Science literacy (PISA)	
Fixed effects	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**	**Coefficient (t)**	**S.E.**
Intercept	420.58 (4.86)***	86.61	365.94 (3.41)**	107.40	454.55 (4.76)***	95.39
SES	29.67 (50.29)***	0.59	31.01 (52.55)***	0.59	28.56 (49.24)***	0.58
Gender	−32.35 (−34.78)***	0.93	13.82 (15.53)***	0.89	3.11 (3.62)***	0.86
School use	−15.09 (−30.18)***	0.50	−13.07 (−21.43)***	0.61	−12.91 (−24.83)***	0.52
Home use - school related	5.96 (10.28)***	0.58	6.92 (11.73)***	0.59	5.45 (9.09)***	0.55
Entertainment use	1.38 (3.07)***	0.45	−1.59 (−9.45)***	0.43	0.26 (0.62)	0.42
ICT level	12.68 (2.41)**	5.27	21.61 (3.30)**	6.54	19.14 (3.30)**	5.81
ICT rate of change	−33.33 (−0.71)	47.26	−2.53 (−0.04)	58.68	−29.39 (−6.59)	52.09
ln GDP	1.70 (0.16)	10.41	−1.68 (−0.13)	12.91	−7.11 (−0.62)	11.46
Random effects	**Variance**		**Variance**		**Variance**	
Country-level effect (u_{0j})	441.60		682.87		537.47	
Individual-level effect (r_{ij})	6483.87		6725.40		6340.11	
% of reduced Variance of u_{0j}	59.22%		60.18%		60.31%	
% of reduced Variance of	17.23%		13.92%		12.94%	

*: p<0.05, **: p<0.01, ***: p< 0.001.

ICT level could be explained by the digital divide and its impacts on the achievement gap. The digital divide has been widely used to explain the social implications of the imbalanced accessibility and availability of ICT, as well as the inequality of the possession of ICT-related knowledge and skills necessary to the achievements (Cronin, 2002). It refers to the gap within a geographic area, society, or community between those who have access to information and communication technology and possess the skills to make effective use of these technologies and those who do not have access or such skills (Buente & Robbin, 2008; Hilbert, 2011). The findings in the current research were in alignment with what Huang and Chen (2010) discovered. They analysed the gaps in Internet diffusion across countries and predicted that the global digital divide primarily among developed, developing and under-developed countries would remain deep in the future and continue to widen despite globalization. Due to the shortage of capital investment, developing and under-developed countries lag far behind the industrialized nations in their ICT-industry development and diffusion and are failing to keep pace with the growing ICT race of developed countries. Facing the challenges caused by the digital divide, establishing and implementing a long-term national policy with some viable strategies have thus become essentially necessary. It is well known that access to ICT facilities and efficient usage of these technologies could yield significant benefits for participants, who need to become fully prepared for the future society, allowing people to be competitive in the opportunities for economic growth offered by the information age. Such access could also play a critical role in enabling governments to achieve objectives in electronic service delivery (Cronin, 2002).

According to the results, the influences of national ICT level for both 4th grade and 8th grade students were significantly positive. Given that the achievement instruments were not equated or linked, it is not appropriate to compare the influences on both groups directly. However, considering the scale of the achievement scores, this study did more to highlight a consistently influential pattern for both 4th and 8th grade students than to reveal a profound dissimilarity, so that addressed the significance of the development of national ICT development. Such a finding was quite easy to explain because in the current study, the students in 4th grade in the TIMSS and PIRLS data and in 8th grade in the PISA data were all born during or after the general wide introduction and spread of digital technologies and began interacting with digital technology from an early age (Prensky, 2001; Rudi, 2012; Thomas, 2011). As a result, they may have a better understanding of digital concepts, spend more time on related digital technologies, and be exposed to the ICT environment to a larger extent, compared with their parents or even teachers (Prensky, 2001). From other perspective, they are also the generation receiving quite amount of benefits from the development of the national ICT level; accordingly, they are more likely to be influenced by national ICT levels. This finding also suggested that the influence of national ICT development might remain significant and dramatic as the students grow up, which also points to the importance of the development of the national ICT level.

The ICT development rate of change showed a negative influence on student achievements, despite it not being a significant predictor in all six models. Exploring the relationship between the ICT development rate and national ICT level, an interesting tendency was uncovered: nations with higher national ICT levels tend to have a lower rate of increase of ICT. The negative relationship between these two variables is actually due to how the rate of ICT change was calculated in the current study. Based on the data in 2007 and 2011, the ICT rate primarily measured the change during this period, when most developed countries had already experienced a dramatic revolution in the ICT industry. In contrast, the developing or under-developed countries are still experiencing ICT transfer and adoption. Therefore, the ICT penetration rate for developing and under-developed countries is faster than that for developed countries. To summarize, compared with the ICT development rate, the ICT level demonstrated a stronger influence on student achievements, which also provided additional evidence of the digital divide.

5.2. The influence of individual ICT usage on student achievement

The overall findings in terms of the influences of ICT use seemed complex and inconclusive for 4th and 8th grade students in the current study, which might be due to the reason that two different international datasets were used, where the types of ICT usage were categorized in different ways. Explicitly, the ICT usage for 4th grade students (TIMSS & PIRLS) was divided into home usage and school usage; whereas for 8th grade students (PISA), it was grouped into home usage for educational purposes, school usage, and usage for entertainment. Another possible explanation is the measurements in different international assessments. In terms of PISA, it was designed to assess the extent to which 15-year-old students could apply what they learnt in real life and whether they were prepared for the future, whereas TIMSS and PIRLS are more related with school curriculum, with the aim of providing more suggestions for national education decision and policy making.

Consistent positive influences for the two types of ICT usage (at school and at home) were discovered for all three subjects on 4th grade students, which was contradictory with the findings from previous large-scale studies using TIMSS and PIRLS data (Jager, Bos, & Velde, 2008). They claimed that the intensity of ICT use at home was negatively related to learning performance. Similarly, Eickelmann, Drossel, Wendt, and Bos (2012) also found that frequent computer use was correlated with low achievement among the TIMSS 2007 participants because low achievers were more likely to use computers at schools, e.g., training software, to make up for the low progress. One possible explanation for the controversial findings might be the incongruent items across years. In 2011, only one general question about the frequency of usage at home/school was asked, which encompasses a broad concept of ICT usage. However, in previous years, more specific questions concerning the activities of ICT learning were employed.

For 8th grade students, the three different forms of ICT usage were found to be significant predictors, but with different influential directions. ICT usage at school showed a negative influence on students' academic performances; in other words, more frequent ICT usage in school was related with lower achievements. However, if students tended to use ICT more frequently at home for working on school-related tasks, their achievements were more likely to be better. This phenomenon was also found by Delen and Bulut (2011) with Turkish students using the PISA 2009 dataset. As Lowe, Krahn, and Sosteric (2003) explained, “the family context becomes the determining factor in how useful computers will be in a student's future educational or work career” (p.152) (cited from Luu & Freeman, 2011). Cheema and Hang (2013) also explained the small but negative effect of education-software use on achievement. Because specific computer programs affect very narrow areas of learning, they may not have a strong direct association with learning outcomes. In addition, ICT use for entertainment purposes showed positive predicting effects on both reading and math but a significant negative influence on science. Similarly, Gumus and Atalmis (2011) also found that ICT use for entertainment purposes positively predicts student achievements in reading. ICT is developing rapidly, and students are becoming engaged in more and more ICT usage. Diverse ICT equipment such as computers or Internet access no longer exclusively plays educational roles among students. Chatting online, playing games, listening to music and watching movies have become the most frequent activities. Some researchers (Cheema & Hang, 2013) have argued that spending too much time on these specialized programmes may significantly and negatively affect other domains of learning, leading to the small positive effect being completely overcome by a large negative effect. As a result, further exploration regarding the influences of entertainment ICT activities on students' academic outcomes is still needed.

6. Conclusion

The main contribution of this study is new knowledge about the relationship between national ICT development and individual skills. The results of the present study showed that the national ICT level was a significant positive predictor for individual skills among 4th and 8th grade students. Because the positive effect of the level of ICT can be explained by the relationship between the digital divide and the achievement gap, recommendations for bridging the digital divide should be given to national/international organizations and other international education stakeholders. Recommendations for national ICT/education policies should be provided as well. The results of the present study also indicated that ICT use showed mixed influences on three subjects for all groups of individuals, depending on the different types of ICT usage. Therefore, more research needs to be done to explore how different types of ICT use will affect individual achievement as well as the direction of these effects. Nevertheless, ICT should be used carefully in education, especially in compulsory education.

Several limitations related with the current analysis were discussed and have implications for future studies. Given the cross-sectional nature of the datasets used in this research, we intended only to explore the association between variables, cautious that no causality implications should be drawn. Future research should also include data not only from international surveys but also from other ICT-in-education initiatives with an experimental design to determine cause-and-effect relationships. The second limitation related with the impacts of GDP on student achievements. Even the national GDP was controlled; it was found out that the influences of GDP in model 1 and 2 were completely contradictory. With the aim to identify the reasons why this could happen, further exploratory analyses were conducted. It was observed that the national GDP and ICT development level were highly correlated with each other, with coefficients of 0.70 or above which might cause the problem of multicollinearity. However, it is reasonable since national ICT development level is playing the role of a proxy of national wealth and development level. The third limitation is related with the variables included in the model. Additional data allow us to improve the models tested, e.g., by adding ICT/education variables such as infrastructure, policy, and management, thereby obtaining more significant results.

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