



How Does ICT Use Influence Students' Achievements in Math and Science Over Time? Evidence from PISA 2000 to 2012

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This study aims to investigate the impacts of information and communication technology (ICT) use on students' math and science achievements, with a special focus on examining the trends of these relationships over the past decade. Data from all five waves of the Program for International Student Assessment (PISA) from 2000 to 2012 were used. Three-level hierarchical linear modelling revealed that school-level ICT-related variables had positive influences on learning outcomes when national GDP, school type, and school ICT investment, were controlled for. However, the findings indicated that the relationships between different types of ICT use with math and science achievement were negative in the long term when students' families' social economic status was held constant. In addition, self-confidence in Internet tasks was discovered to be beneficial to both math and science, and thus, suggestions were made to develop students' confidence in conducting ICT-related activities.

Keywords: ICT use, mathematics and science education, student achievement

INTRODUCTION

Information and communication technology (ICT) is a specific term that refers to technologies designed for collecting, processing, preserving and delivering information (Elisha 2006). It has been widely recognized that the rapid development of ICT dramatically affects every aspect of contemporary life by changing the ways people live, work, and study in today's knowledge society. These changes have brought innovative and diverse options, but they have also required us to be information and communication technology (ICT) literate. In general, ICT literacy is defined as the ability to use technology tools appropriately in processing, managing, and evaluating information and communicating with others (ETS 2004; MCEETYA 2006).

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In the area of education, a growing body of evidence demonstrates that ICT is an effective means for addressing education goals and requirements (Flores and Lin 2013; Guzeller and Akin 2014; Vanderlinde, Aesaert, and Braak 2014). Therefore, the effects of integrating ICT into teaching and learning on students' development have gained more and more attention from both education policy makers and researchers (Ponzo 2010; Luu and Freeman 2010; Aypay 2010; Gumus and Atalmis 2011). However, given that students have more access to computers and the Internet at both home and school, the question of whether students' personal ICT use is beneficial for outcomes, especially academic achievement has also been explored (McMahon, Yeo, and Williams 2011).

Since 2000, students' ICT use has been included as an additional item on the PISA survey (Programme for International Student Assessment) in all five waves. The main focus of the survey is to establish how often and how well students use different ICTs, such as for word processing, spread sheets, and editing, for processing or transmitting digital information, or for email or other communication tools (OECD 2003). In addition to these basic operational skills, students' attitudes and confidence regarding ICT are also measured in the PISA survey.

By using the data from all five waves of PISA, the current study aims to explore the trends in ICT use related to students' achievements in math and science over time. PISA's design not only allows for comparing countries by learning outcomes but also enables monitoring changes over time. By comparing and contrasting the influences of the various ways in which students use ICT on their performance each year, two primary research questions will be answered: 1) how students' ICT use and self-confidence influence their math and science achievements and 2) whether the influences of ICT use on individuals change over time.

BACKGROUND

Measuring and Categorizing ICT Use

The high demand for ICT literacy became the primary driver of large-scale national and international attempts to measure it. However, it has become clearly that the direct measurement of ICT literacy is very difficult, especially using large-scale tests (Zhong 2010; Oliver and Towers 2000; Ainley, Fraillon, and Freeman 2007). Given that surveys can be consistently administered to large numbers of respondents across large geographic areas (Ainley, Fraillon, and Freeman 2007), additional ICT questionnaires have been used to evaluate the frequency of students' computer and

State of the literature

- ICT usage has been regarded as an important indicator of ICT literacy. According to the philosophy of constructivism, ICT has provided students with more opportunities to explore the world by themselves.
- Previous researches produced mixed findings regarding with the relationship between student ICT usage and their academic performance, which highlighted the importance of differentiating the purpose of ICT usages while investigating such relationship.
- The most widely used method of categorizing ICT use is to differentiate the purpose for entertainment from those for education. However, the relationships between different type of ICT usage and student academic achievement were found inconsistent.

Contribution of this paper to the literature

- The most important contribution of this research is to add to the literature by investigating the trends of the influence of ICT use on student performance over time through using the PISA data from 2000 to 2012.
- The current research shed light on the complex influences of ICT use by investigating a broad spectrum of participants worldwide. Therefore, this study's findings have better generalizability.
- By running three-level HLM, different confounding variables were controlled at different level, thus the findings are very helpful for better understanding how diverse ICT uses influence student achievement in both math and science.

Internet use to conduct various activities, as well as their attitudes towards using ICT. All of these questions have been regarded as important components of ICT literacy and also considered indicators of ICT literacy (OECD 2011; Oliver and Towers 2000).

Because ICT use has been regarded as an important indicator of ICT literacy, examining its attributes has become very important. From the perspective of the philosophy of constructivism, which emphasizes the importance of learning contexts (Pea 1997; Young 2008), students generate and produce knowledge and ideas through interactions with society and the environment. Interaction with society emphasizes collaborative efforts between students and teachers, and classmates to achieve shared goals. Interaction with materials refers to the designed ICT artefacts, such as computers, tools, and databases, as well as symbols. According to these theories, as ICT develops rapidly and ICT investments increase dramatically, advanced ICTs support has extended students' learning environments. As a result, students' engagement in ICT activities gives them the opportunity to learn more ICT knowledge and skills, master specific ICT tools, access current knowledge, and just generally positively influence their lives (Pea 1997; Young 2005, 2008; OECD 2011; Zhong 2010; Guzeller and Akin 2014).

Researchers have reached a consensus that it is necessary to differentiate between different types of ICTs in examining ICT use and academic performance (Grinager 2006; Honey, Culp, and Spielvogel 1999; Wainer 2008; Lei and Zhao 2007; Papanastasiou 2003). ICTs can be used for many different purposes, such as entertainment and education (Ziya, Dogan, and Kelecoglu 2010; Papanastasiou and Ferdic 2006; Ravitz, Mergendoller, and Rush 2002; Luu and Freeman 2011; Gumus and Atalmis 2011). Regarding its entertainment aspects, students actively participate in diverse computer and Internet activities, such as chatting online, playing games, and watching movies. However, students also actively engage with computers and appropriate technologies for school- and education-related tasks, for example, searching the Internet for information, downloading class materials from school websites, and improving their learning efficacy and methods using certain software. ICT use could also be categorized by locations, that is, whether ICT activities take place, at home or at school, or elsewhere (OECD 2011; Delen and Bulut 2011). In recent decades, school-level ICT investments in equipment and infrastructure has advanced from providing televisions in classrooms to providing Internet access for online teaching and learning (Blackwell, Lauricella, and Wartella 2014). Meanwhile, families are playing greater roles in transmitting ICT influences now that so many students have their own computers and can easily access the Internet at home. ICT use can also be classified into other categories; some researchers group ICT activities into gaming, collaboration and communication, information and technical operations, knowledge and content creation and problem solving (Biagi and Loi 2012).

The Relationship between ICT Use and Student Achievement

The development of ICT use in education settings has not only become a policy priority in most countries but also triggered a flurry of research studies that focus on the relationship between ICT and academic achievement. In particular, a large number of researchers have used national or international assessment data, such as from the PISA, TIMMS, NAEP, PIRLS, and ELS2002, to explore this relationship. However, the previous research on the influences of ICT use on learning has unfortunately not produced consistent results (Song and Kang 2012; Wainer et al. 2008; Luu and Freeman 2011; Spiezia 2010).

A number of studies found that computer availability and use had positive effects on students' achievement (Chang and Kim 2009; Notten and Kraaykamp 2009; Guven and Kosa 2008; Li et. al. 2012; Luu and Freeman 2011; Kubiak and Vlckova 2010; Spiezia 2010; Demir and Kilic 2009) and highlighted that it was critical to develop

students' skills in using computers and advanced communication technology in order to improve their learning outcomes (Lee 2009). Other researchers (Paton 2010; Sullivan 2005; Papanastasiou 2002; Fuchs and Woessman 2004; Wittwer and Senkbeil 2007; Aypay 2010), however, found negative correlations between computer use and students' achievement. For example, Wittwer and Senkbeil (2008) found that computers had no substantial influence on math performance.

These mixed findings could be due to fact that the relationship between ICT use and learning achievement is mediated by other backgrounds and process-related variables (Song and Kang 2012). Therefore, some researchers have suggested further exploring the relationships between ICT use and learning achievement but taking other relevant variables into account, such as the purpose of ICT use given that different uses affect students' achievement in different ways (Luu and Freeman 2011; Lee and Wu 2012; Gumus and Atalmis 2011). However, studies on the relationship between ICT use and academic achievement in terms of different purposes have still found no consistent results.

The most widely used method of categorizing ICT use is by purpose, specifically for entertainment or education. In some research, using ICT for entertainment was found to positively influence achievement because entertainment can help students release stress and passive emotions so that they can concentrate on learning and enable students to think effectively and critically, which is necessary for their learning (Witter and Senkbeil 2008; Ziya, Dogan, and Keleciloglu 2010). In contrast, some researchers have found that excessive ICT use for entertainment may lead students to neglect their studies and can even lead to addiction, thus negatively influencing students' achievements (Luu and Freeman 2011). However, other researchers (Ziya et al. 2010) found no significant effect between using ICTs for entertainment and math scores. One of the most important contributors to these disparate is that across studies, ICT use for entertainment produced different effects on different subjects. For example, within the same Turkish group and the same 2006 PISA dataset, Gumus and Atalmis (2011) found that using computers for entertainment positively affected reading scores, but Anil and Ozer (2012) found that the correlation between students' use of computers for fun and their science achievement was significant but negative. Similarly, Luu and Freeman (2011) also found a negative association between ICT use for entertainment and science achievement in both Canada and Australia using the 2006 PISA dataset. Certainly, with the rapid development of ICT, students' ICT has also changed dramatically, which could be changing ICT's influences on them. For example, using the more recent 2009 PISA dataset, Biagi and Loi (2013) discovered that gaming showed positive influences on PISA test scores in all three subjects.

Because the most important initial intention of integrating the ICT into teaching and learning is to improve students' academic performance, many studies have been devoted to finding evidence regarding the relationship between ICT use for education purposes and student achievements. Unfortunately, the findings have been quite complex in that some researchers have supported the positive influences of ICT use on achievement (Luu and Freeman 2011; Bielefeldt 2006; Ravitz, Mergendoller, and Rush 2002; Flores, Inan, and Lin 2013), but others have found the opposite (Papanastasiou et al. 2003; Gumus, Atalmis, and Hasan 2011; Ziya, Dogan, and Keleciloglu 2010; Papanastasiou and Ferdic 2006; Witter and Senkbeil 2008); these latter studies reported that students were spending time on ICT activities that were completely unrelated to learning. For example, again using the PISA 2006 data, Aypay (2010) found an entirely non-significant relationship between ICT use for education purposes and math, but Anil and Ozer (2012) found a positive correlation between them. Such mixed findings could be highlighting challenges related to effectively integrating ICTs into course content.

With the aim of establishing the influence of ICT use for education more clearly, some studies have categorized education-related ICT use into whether it takes place

at home or at school and explored its effects separately by location. The distinction is whether students are using ICTs to complete school-related tasks such as homework, online information searches, and project preparation in their homes versus at their schools. There, the debate regarding which if either location has a more important influence on students is ongoing. Delen and Bulut (2011) investigated Turkish students using the 2009 PISA dataset and indicated that students' exposure to ICT outside of school time had a larger impact on their math and science achievements than their exposure at school. In alignment with this finding, Bielefeldt (2006) indicated the negative influence of ICT use for education purposes at school, especially among high-frequency users, but a positive effect of using educational software at home. Similarly, Papanastasiou, Zembylas, and Vrasidas (2003) found a negative relationship between using educational software at school and science scores. They also provided the explanation that students receiving computer-assisted instructions are more likely to be the low achievers or to have difficulties keeping up with their classmates.

Meanwhile, a significant amount of research has found that students' demographic variables such as gender and socio-economic status greatly impact their computer use (Papanastasiou, Zembylas and Vrasidas 2003; Livingstone 2007; Javier et al. 2012; Aypay 2010), as well as their academic performance (Witter and Senkbeil 2008; Luu and Freeman 2011). A large number of studies have focused on gender differences in learning and ICT use; for example, it was found that girls behaved better during ICT activities than did boys (Ong and Lai 2006). However, in terms of the relationship between ICT use and student achievement, there is no statistically significant difference between male and female students (Gumus and Atalmis 2011; Luu and Freeman 2011).

Rationale for the Current Study

In recent years, the amount of research in this area has increased as interest in measuring ICT use through large-scale international assessments has also enhanced. Since 2000, the PISA survey has become one of the most commonly used data sources for investigating this question. However, the studies on this topic even using the same PISA datasets have reported mixed findings. The inconsistencies could be attributable to variations in study focus; for example, most studies only explored one specific subject with the data from only one test round, or focused on a particular student group from only one country or a small number of countries. Such inconsistent findings can only provide limited information for understanding the overall impacts of ICT use on student achievement. Another possible explanation is that different analysis methods and models with varying controls have been used in different studies and as a result, the final findings across different studies are not actually comparable.

In addition, over the past five assessment waves, PISA's measurements of ICT use have changed. In general, compared with PISA 2000, the subsequent four cycles' questionnaires were more detailed and specific. In terms of programs and software, as ICT has developed rapidly, the diversity of available applications has expanded dramatically as well, from simple early tools such as word processing, spreadsheet, drawing, painting, and processing tools to more advanced tools such as programming software and education-related software for learning. Regarding, for example, frequency of Internet for entertainment, only three items were included on the PISA 2000 questionnaire, but the following rounds incorporated more items that encompassed a variety of activities to measure students' ICT use and behaviours.

Therefore, the current study aimed to fill the existed gap in the prior research by examining the potential trend of ICT influence over time through investigating the PISA data from all five waves. A multilevel model that incorporates both school-level

and individual ICT use while controlling for similar variables can be employed to explore the trends in the influences of different types of ICT use on individual student performance. In addition, by encompassing all of the countries that participated in the ICT survey, findings based on a broad global spectrum of participants could help us understand the complex influences of ICT on students' mathematics and science achievements.

METHODOLOGY

Data and Participants

The data for the current study came from all five PISA cycles, which were published on the OECD website. PISA is a cross-national, large-scale assessment that has been conducted every three years since 2000; the most recent cycle was in 2012. PISA aims to assess 15-year-old students' performance in math, reading, and science, and it also collects contextual data about students' demographic information, their learning attitudes and behaviours, their parents, and their schools. In addition, each country had the option of completing a questionnaire that measured students' familiarity with ICT.

ICT is administered as an additional survey in PISA test; therefore, the countries that volunteered to participate in each cycle have differed. However, increasing numbers of countries have completed the ICT questionnaire since the first cycle: 25 in PISA 2000, 32 in PISA 2003, 40 in PISA 2006, 45 in PISA 2009, and 43 in PISA 2012. Each country that completed the ICT questionnaire in all five cycles was included in this study, for total samples of 148987 students in the 2000 data, 228154 in 2003, 267242 in 2006, 316128 in 2009, and 280520 in 2012.

Variables

A three-level hierarchical linear model was applied to investigate the relationship between students' ICT use and their achievement. Separate models and analyses were conducted for each dependent variable. Students' math and science literacy scores were used as the dependent variables. There were three levels of independent variables: country, school and student. These variables are described in detail below.

Country-level Variables

In recent years, information and technology development has become an extremely important indicator of countries' development levels (Guzeller and Akin 2014), but it should be noted that digital gaps remain in different countries' development levels. The term digital divide describes gaps in ICT access, using skills and knowledge (Norris 2011). The OECD (2011) has suggested that there is a digital-access divide between developed and developing countries. To examine the global digital divide, national GDPs taken from World Bank data were controlled for at the country level. With the aim to reduce the problem of skewness, the log transformation was applied to the GDP. Higher LnGDP values means better country economic status.

School-level Variables

The school level contains two primary variables, school-level economic status and school type, and school-level ICT development indices (i.e., quality of schools' educational resources and the ratio of instructional computers to total computers). School-level economic status was calculated by aggregating student-level social economic status. School type was also included in this study; in the PISA dataset, the school type variable is labelled "SCHLTYPE" (1="Private independent"; 2="Private government-dependent"; 3="Public"). COMPWEB is the ratio of the number of computers for instruction that are connected to the web to the number of computers

for education purposes that are available to 15-year-old students. The index of the school's educational resources (SCMATEDU) was computed on the basis of seven items that measured school principals' perceptions of potential factors that could hinder instruction at their schools. Higher scores indicate better-quality educational resources (OECD 2012), and the seven items that are rated include shortages of instructional materials or inadequate materials, computers for instruction, Internet connectivity, and educational software, in addition to other resources. Both indices (COMPWEB and SCMATEDU) were used to describe the quality of school-level ICT infrastructures.

Student Variables

Both demographic and ICT use-related variables were included at the student level. Two variables that indicated student background were used as the controlling variables in the models, social economic status (ESCS) and gender (1="female"; 2="male"). On the PISA ICT questionnaire, students are asked whether and where they have access to a computer and Internet, how long they have been using ICT, how frequently they use their computers and Internet, their self-efficacy in using computers, and their general interest in using computers. The dimensions of PISA's ICT questionnaires from 2000 to 2012 are not the same; compared with PISA 2000, the latter four cycles' questionnaires have been more detailed, diverse, and specific. To make the results comparable, we attempted to identify the questions that were similar across all five cycles, which were, generally, frequency of internet use for education and for entertainment, program and software use, and confidence in using ICT. This study aimed to compare the results from all five rounds to determine how ICT use has influenced academic performance over time. With the goal of making the variables and their calculations consistent, the OECD's existing indices were used in the study. Besides, The ICT use-related variables, including frequency of internet use for education and for entertainment, program and software use, and confidence in using ICT, were all component scores. Higher value indicated more frequent usage and higher confidence in using ICT.

Frequency of Internet use for entertainment was measured in all five cycles, but the items were different. Only three items without noting particular activities were included on the PISA 2000 questionnaire. On the subsequent questionnaires, the magnitude and number of items increased with more specifications on particular activities such as information searching, for fun, for downloading and uploading music. Six items were included in both 2003 and 2006, eight in 2009 and ten in 2012. On PISA 2009 and 2012, one noteworthy change was that Internet use was given more attention, particularly related to learning, such as using the Internet to email and communicate with classmate and teachers, download and upload school material, and conduct simulations. There were no significant changes from 2000 to 2006 in assessing the frequency of program and software use; the indicators in each cycle included word processing, spreadsheet, drawing, painting, programming, and educational software and school materials.

In terms of confidence in performing ICT tasks, two types, Internet related and high-level task related, were both measured in 2003 and 2006, but only high-level tasks were measured in 2009. Confidence in performing Internet-related tasks relates to self-efficacy in operations such as copying and downloading files and sending emails. High-level tasks include using software for advanced operations such as word processing, using spreadsheets to plot graphs, creating presentations, eliminating computer viruses, building web pages, etc.

Data Analysis

A three-level hierarchical linear model was used to investigate the relationship between students' ICT use and achievement, with demographic variables controlled

for at the individual level, school background variables controlled for at the school level, and national GDP controlled for at the country level. HLM has been widely used to predict dependent variables using multiple independent variables at different levels and to examine the dynamics between micro and macro levels (Raudenbush and Bryk 2002) because its advantages in resolving the problems associated with traditional regression analysis, such as aggregation bias and underestimated standard errors (Lee 2000).

In the HLM analyses, first a null model with no covariates was build in order to investigate how much variance in students' achievement could be attributed to within- and between-group components (Willms and Smith 2005). Intra-class correlations (ICCs), which quantify the resemblance between cases from the same country levels, were calculated. Sufficiently high ICCs would have indicated that HLM was appropriate for this three-level analysis. Second, the variables at all three levels were added to the null model to establish the full model. Because of the multistage cluster sampling, balanced repeated replication (BRR) with 80 replicates was employed to estimate the PISA sampling errors. The models were analysed using SAS software. The final three-level HLM models are as follows:

Level-1 model :

$$Y_{ijk} = \beta_{0jk} + \beta_{1jk} * ESCS + \beta_{2jk} * GENDER + \beta_{3jk} * PRGUSE + \beta_{4jk} * INTUSE + \beta_{5jk} * HIGHCONF + \beta_{6jk} * INTCONF + r_{ijk}$$

Level-2 model :

$$\begin{aligned} b_{0jk} &= g_{00k} + g_{01k} * (ESCS_school) + g_{02k} * SCHLTYPE + g_{03k} * COMPWEB + g_{04k} * SCMATREDU + u_{0jk} \\ b_{1jk} &= g_{10k} \\ b_{2jk} &= g_{20k} \\ b_{3jk} &= g_{30k} \\ b_{4jk} &= g_{40k} \\ b_{5jk} &= g_{50k} \\ b_{6jk} &= g_{60k} \end{aligned}$$

Level-3 model :

$$\begin{aligned} \gamma_{00k} &= \pi_{000} + \pi_{001} * LnGDP + \varepsilon_{00k} \\ \gamma_{01k} &= \pi_{010} \\ \gamma_{02k} &= \pi_{020} \\ \gamma_{03k} &= \pi_{030} \\ \gamma_{04k} &= \pi_{040} \end{aligned}$$

where:

Y_{ijk} is the math and science scores for individual i at school j in country k ;

b_{0jk} is the expected math and science scores for an individual at school j in country k ;

β_{1jk} is the expected slope of ESCS for individuals at school j in country k ;

β_{2jk} is the expected difference between female and male at school j in country k ;

β_{3jk} is the expected slope of PRGUSE for individuals at school j in country k ;

β_{4jk} is the expected slope of INTUSE for individuals at school j in country k ;

$\beta_{5,jk}$ is the expected slope of HIGHCONF for individuals at school j in country k ;
 $\beta_{6,jk}$ is the expected slope of INTCONF for individuals at school j in country k ;
 r_{ijk} is a unique error associated with individual i at school j in country k ;
 g_{00k} is the expected math and science scores for a school in country k ;
 γ_{01k} is the expected slope of ESCS_school for schools in country k ;
 γ_{02k} is the slope of SCHLTYPE for schools in country k ;
 γ_{03k} is the slope of COMPWEB for schools in country k ;
 γ_{04k} is the slope of SCMATEDU for schools in country k ;
 π_{000} is the expected math and science scores across all countries in the sample;
 π_{001} is the expected slope of LnGDP; and
 ε_{00k} is a unique error to the intercept associated with country k .

RESULTS

Descriptive analysis

The descriptive statistics and the final sample size of variables of three levels were presented in Table 1. According to the PISA technical report, all the ICT-related variables were standardized at the scale with the mean of an OECD average of 0 and an OECD standard deviation of 1. For non-OECD, the scales were determined separately. Given that the data from each year were analyzed separately, the means were not comparable. In the current research, both OECD and non-OECD countries were included. Therefore, it could be observed that the means were deviated from 0 slightly.

Table 1. Descriptive statistics

variables	2000			2003			2006			2009			2012		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
GDP	148987	9.43	1.06	228154	9.62	0.87	267242	9.97	0.86	316128	10.14	0.74	280520	10.16	0.76
ESCS_school	148736	-0.32	0.73	227463	-0.13	0.71	267177	-0.06	0.64	315945	-0.07	0.64	280276	-0.22	0.72
COMPWEB	106351	0.48	0.38	198562	0.71	0.35	255829	0.83	0.27	290647	0.94	0.19	259905	0.94	0.20
SCMATEDU	144320	0.14	1.06	223015	-0.11	1.06	261758	-0.09	1.02	311311	0.05	0.99	271057	-0.07	1.07
ESCS	147148	-0.32	1.07	224675	-0.14	1.06	264577	-0.06	1.01	312010	-0.07	1.01	276097	-0.22	1.07
Program/software(PRGUSE)	115644	-0.02	1.04	202101	0.04	1.02	255591	0.10	1.02					-0.08	1.07
Internet for fun (INTUSE)	112841	0.00	1.00	202957	-0.01	1.05	255801	0.01	1.04	300511	-0.05	1.09	265942	-0.08	1.07
for education at school(SCHUSE)										304350	0.01	1.01	264204	0.00	1.02
for education at home (HOMUSE)										304240	-0.03	1.04	263459	-0.05	1.02
High-level tasks				201412	-0.01	1.01	255092	-0.02	1.01	302852	0.02	1.01			
Internet tasks				201063	-0.09	1.08	255504	-0.11	1.08						

HLM Analysis of the Effects of ICT Use on Student Achievement

For the null model, ICCs were calculated in order to examine whether the variances were significant between countries and schools. The results showed that the ICCs for the 5 cycles for both math and science ranged from 13% to 26%, which indicated that approximately 20% of the total variance could be explained by the differences among countries and schools, which in turn necessitated running the hierarchical linear models.

Based on the null models, random intercept models that included the student, school-, and country-level predicting variables were established to estimate the effects of different factors on students' math and science achievements across the five

survey rounds while controlling for other relevant background information (see Table 3 and Table 4). We examined the results of the final models to identify the significant influential variables from the different levels. In the final full model, up to 80% of the country-level variance, 60% of the school-level variance, and 10% of the

Table2. Intraclass coefficient for math and science across five testing runs

		2000	2003	2006	2009	2012
Math	Intercept(country)	3073.23	2055.51	2427.42	2183.20	2092.71
	Intercept(school)	2786.67	2727.76	2975.68	3050.39	3090.62
	residual	5862.25	5588.23	4959.89	4742.66	4702.25
	ICC for country	26.22%	17.53%	20.71%	18.62%	17.85%
	ICC for school	23.77%	23.27%	25.39%	26.02%	26.36%
Science	Intercept(country)	1817.44	1426.43	2807.51	1763.87	1530.25
	Intercept(school)	2468.88	2665.17	2858.26	3045.61	2896.92
	residual	5910.79	6871.72	5382.03	5105.09	4522.04
	ICC for country	15.50%	12.17%	23.95%	15.05%	13.05%
	ICC for school	21.06%	22.74%	24.38%	25.98%	24.71%

Table3. The Random Intercept Model for Students' Math Literacy

		2000 Coefficient(t)	2003 Coefficient(t)	2006 Coefficient(t)	2009 Coefficient(t)	2012 Coefficient(t)
Fixed effects						
Country level						
	LnGDP	-1.74(-0.28)	2.32 (0.48)	-0.34 (-0.05)	8.65(1.07)	9.89(1.09)
School level						
	ESCS_school	54.65*** (27.32)	60.91*** (70.05)	58.79*** (108.32)	60.60*** (118.32)	59.63*** (97.57)
	School type	9.26*** (8.11)	13.21*** (25.25)	10.25*** (33.34)	7.16*** (24.70)	11.53*** (38.03)
	COMPWEB	9.06*** (6.35)	10.74*** (13.02)	7.93*** (10.64)	7.30*** (6.99)	-14.63*** (-15.31)
	SCMATEDU	-1.37*** (-3.26)	2.01*** (9.67)	1.36*** (6.52)	2.51*** (16.79)	1.87*** (10.97)
Student level						
	ESCS	19.98*** (9.92)	18.77*** (26.50)	13.91*** (31.60)	15.49*** (37.05)	12.46*** (31.10)
	Gender	16.29*** (7.68)	15.14*** (14.57)	16.27*** (24.98)	15.60*** (19.83)	15.09*** (23.94)
ICT-usage						
	Program/software(PRGUSE)	-4.77** (-2.90)	-3.23*** (-5.48)	-3.17*** (-6.44)		
Internet	for fun (INTUSE)	-1.10(-0.62)	-7.50*** (-10.20)	-9.60*** (-18.35)	-0.88* (-2.45)	0.78* (2.24)
	for education at school(SCHUSE)				-8.69*** (-28.68)	-9.46*** (-27.82)
	for education at home (HOMUSE)				-3.71*** (-8.89)	0.41(0.94)
ICT-confidence						
	Highlevel tasks		0.10(0.14)	5.18*** (9.93)	6.49*** (18.05)	
	Internet tasks		9.98*** (14.63)	9.83*** (18.86)		
Random effects						
	Country-level effects (variance reduced)	1108.53(63.93%)	547.02(73.39%)	1538.00(36.64%)	1887.63(13.54%)	1622.74(22.46%)
	School-level effects (variance reduced)	1443.45(48.20%)	925.31(66.08%)	1267.53(57.40%)	1329.95(56.40%)	1201.84(61.11%)
	Student-level effects (variance reduced)	5390.92(8.04%)	5057.83(9.49%)	4577.13(7.72%)	4363.31(8.00%)	4460.63(5.14%)

student-level variance was explained by the combination of all of the variables from all three levels. In addition, as the Table 3 & 4 showed, adding more predictors at all three levels could dramatically reduce the variance to certain extent. Compared with the variance at student level, the variance at the school and country level were reduced at a higher extent. The contributions of the predictors from each level were as follows.

Table 4. The Random Intercept Model for Students' Science Literacy

	2000 Coefficient(t)	2003 Coefficient(t)	2006 Coefficient(t)	2009 Coefficient(t)	2012 Coefficient(t)
Fixed effects					
Country level					
LnGDP	-9.04(-1.80)	-5.74(-1.17)	-4.81(-0.82)	3.39(0.46)	5.72(0.76)
School level					
ESCS_school	53.73*** (33.19)	59.89*** (44.87)	57.55*** (102.40)	58.67*** (113.20)	54.91*** (104.36)
School type	10.52*** (11.53)	13.46*** (24.16)	10.05*** (29.69)	6.94*** (19.22)	9.83*** (33.77)
COMPWEB	8.76*** (5.44)	10.04*** (10.31)	8.52*** (10.45)	11.16*** (13.97)	-11.71*** (-11.93)
SCMATEDU	-1.85*** (-3.45)	1.72*** (7.30)	1.11*** (6.37)	2.51*** (13.96)	1.57*** (5.60)
Student level					
ESCS	16.52*** (10.77)	21.52*** (23.02)	14.04*** (33.22)	14.99*** (31.95)	11.59*** (28.05)
Gender	-1.26 (-0.49)	12.29*** (11.17)	7.84*** (11.86)	3.34*** (4.49)	5.74*** (8.74)
ICT-usage					
Program/software(PRGUSE)	-4.57*** (-2.88)	-3.13*** (-4.07)	-4.25*** (-9.06)		
Internet for fun (INTUSE)	-2.77(-1.60)	-8.88*** (-9.31)	-9.98*** (-22.47)	-1.22*** (-3.28)	2.12*** (6.10)
for education at school(SCHUSE)				-7.92*** (-24.65)	-9.25*** (-25.57)
for education at home (HOMUSE)				-4.74*** (-12.81)	-0.60(-1.62)
ICT-confidence					
Highlevel tasks		-0.15(-0.16)	-4.93*** (8.72)	7.58*** (22.57)	
Internet tasks		11.07*** (12.55)	10.92*** (21.32)		
Random effects					
Country-level effects	686.58(62.22%)	563.66(60.48%)	1098.97(60.86%)	1546.65(12.31%)	1328.05(13.21%)
School-level effects	1226.41(50.33%)	905.22(66.04%)	1143.12(60.01%)	1230.85(59.59%)	1331.84(54.03%)
Student-level effects	5447.56(7.84%)	6295.02(8.39%)	4911.39(8.74%)	4766.38(6.3%)	4270.61(5.56%)

At the country level, the results obtained using the 3-level HLM indicated that national GDP had no significant impacts on student learning outcomes, with ambiguous relationship directions between the two while controlling for school-level predictors that indicated the quality of schools' computer infrastructures and their average social economic statuses. Specifically, in both 2009 and 2012, the relationship between GDP and achievement was positive, but in the previous rounds, the relationships were negative even though the controlling variables remained the same; the only exception was for math in 2003.

At the school level, both school type and school average social economic status were found to show consistently and significantly positive relationships with student math and science achievement across all five cycles. The schools with higher average SES levels were more likely to indicate higher student achievement. In the first four cycles, from 2000 to 2009, the COMPWEB index, which indicates schools' Internet access, was found to have a significantly positive influence on student achievement in both subjects. However, it turned to be a significant and negative factor in 2012 for both math and science achievement. In contrast, the index for schools' educational resources (SCMATEDU) was found to be a significantly positive factor for both math and science, with the only exception in 2000.

At the student level, family social economic status was found to be a consistently and significantly positive influence on student achievement in all five cycles. That is, students who have higher SES levels tend to show higher achievement indicators. Male students on average achieved higher levels of performance in both math and

science, and the differences were all significant except for science in 2000. It was found that in all five cycles, the gender gap was far greater for math than it was for science. For math across all countries, males outperformed females by 15 points on average, which was nearly one-third of the standard deviation. In contrast, the average gap for science ranged from 4 to 12 points, although it still favoured male students.

In terms of ICT-related variables, two broad types of activities were investigated on PISA surveys, program and software use and Internet use. Frequency of program and software use was measured as an important ICT use indicator in three of the five testing rounds, 2000, 2003, and 2006. It was found that this type of use had a significantly negative influence on student achievement in both math and science, suggesting that students' time spent using ICT programs and software did not necessarily correlate with higher academic performance.

For Internet use, two subtypes of activities were identified by purpose. In the current study, it was also found that the two types of activities had differing levels of influence on student academic performance. Frequency of Internet use for entertainment was an important topic that was assessed in all five PISA cycles, although the specific content was modified slightly over time. According to the HLM analysis, the extent to which students used the Internet for entertainment had significant impacts on their achievement in both math and science, with the only exception in 2000, when the results were not significant. From 2000 through 2009, the intensity of students' engagement in Internet entertainment activities had significantly negative relationships with their academic performance in both subjects. However, in 2012, the influence was positive. The second type of Internet use was for education purposes, and this was only measured in 2009 and 2012, although this category was subdivided into whether the Internet was used at home or at school. In 2009, Internet use for education purposes had a significantly negative influence on achievement in both subjects no matter whether it took place at school or at home. In 2012, however, the impact of this type of Internet use did differ. Use at school still had a significant negative influence on student performance, but for use at home, non-significant positive and negative relationships, respectively, were found for student achievement in math and science.

In three PISA rounds (2003, 2006, and 2009), confidence in performing ICT-related tasks was also measured in the model in addition to frequency of use, and confidence was also categorized into two task types: Internet and high-level. Student confidence in performing Internet tasks consistently showed beneficial effects on achievement in both subjects. In contrast, the relationships between students' confidence in performing high-level tasks and their achievement were mixed across years and subjects. Regarding math achievement, it was found that students with more confidence tended to have higher scores, although this relationship was significant in 2006 and 2009 but not in 2003. In terms of science, higher confidence was found to be a significant positive factor only in 2009.

DISCUSSION

The most important contribution of this research is to add to the literature by investigating the trends in the influence of ICT use on individual student performance over time, which has been overlooked in previous studies. By running three-level hierarchical linear models on five PISA testing rounds while controlling for the demographic and background information at different levels simultaneously, this study's results allowed us to identify the changes in the influence of ICT use over the past decade. The findings are very helpful for better understanding how ICT use affected students' learning outcomes from a long-term view. Moreover, it is noteworthy that consistent trends were identified in both math and science among

15-year-old students. Second, the current research shed light on the complex influences of diverse ICT uses on student achievement in mathematics and science by investigating a broad spectrum of participants worldwide; the study included all countries that participated in the additional ICT survey, which previous studies failed to do. Therefore, this study's overall findings have better generalizability and are of particular importance for both education researchers and policy makers.

The Implications of the Changes in PISA's ICT Assessment

Based on the examination of the measurement framework as well as the PISA ICT survey items, three implications of how PISA has changed its ICT assessment are noteworthy, and these also provide information on how ICT use influences student learning outcomes. First, it was found that program and software use was only included in the first three rounds and was given less attention in later waves, whereas Internet use received increasing attention from 2000 to 2012. Across the past five cycles, the content and the dimensions of the Internet use questions has been expanded to be more representative of the wide range of possible Internet activities. This change might have been because as information technologies developed rapidly, students' actual ICT use became more diversified over time. In particular, the dramatic development of the Internet provided more opportunities for students to participate in social communities, access information, and communicate with people around the world (Pea 1997; Young 2008).

Second, the ICT questionnaire responses indicate that as more students come to have their own computers and other devices at home, ICT use is gradually becoming part of their lives. This is quite different from early ICT use, which mostly took place at school. For example, both PISA 2009 and PISA 2012 categorized Internet use for education use by location, at home versus at school. PISA 2012 included three different types of ICT use by location: Internet and entertainment activities outside of school, school-related tasks at home, and school-related tasks at school. Some researchers found that using computers at home was associated with better performance (Wittwer and Senkbeil 2008); when students have, for example, homework difficulties, they can rely on ICT for activities such as searching the Internet for relevant information or communicating with teachers and classmates through email and chat rooms.

Third, earlier ICT skill assessments primarily related to students' use of computers and the Internet for learning and entertainment purposes, whereas in 2009 and 2012, ICTs became media tools for students to interact with other people. School-related tasks focused more on using the Internet to email and communicate with classmates and teachers, download and upload school material, and conduct simulations. According to Young (2005), learning occurs during Internet-mediated activities because of the interwoven relationships between users, the Internet and society. From this view, the Internet could be regarded as a mediating tool between individuals and society (Young 2005) through its promoting interaction and collaboration.

The Influence of Individual ICT Use on Student Achievement

With the aim of obtaining a clearer picture how ICT use affects students' learning performance while adjusting for the influence of relevant background variables, the current analysis made an important distinction between ICT use for two purposes, programs and software and the Internet. The analyses using the hierarchical linear models provided evidence indicating similar patterns for both program and software and Internet use; the relationships between both types of use and student learning outcomes were generally negative over the long term, with the only exception in 2012. At this point, we can argue that students' more frequent ICT use does not

necessarily relate to higher scores. However, given the dramatic changes that are occurring in modern society, this trend could change.

One possible interpretation for the lower achievement with the increased use of programs and software is that basic computer operation skill levels, including word processing, making spreadsheets, are more likely to assist students in completing relevant tasks (Li and Ma 2010). In addition, although ICTs have been widely accepted and integrated into school environments (Hennessy, Ruthven and Brindley in press; Guzeller and Akin 2014; Luu and Freeman 2010), it appeared that the students did not experience any particular advantage from using them. This could have been because educational software was more often used to assist students who were behind, so that it did not show beneficial effects for all students (Karpati 2004). In conclusion, although more specific and diverse program and software use items were included across the different testing rounds, consistently negative associations between this type of use and student achievement were found.

Based on the previous research, the relationship between the frequency of using the Internet for entertainment and student learning performance has been inconclusive, resulting in a great deal of debate. According to the results found in the current study, it appeared that over time, more time spent using the Internet for entertainment did not benefit students' learning outcomes. However, the interesting finding is that the relationship showed a positive sign in 2012: students who used the Internet more often for fun performed better than those who did not. Because 2012 was the turning point, the specific items from 2012 were compared with those from 2009, and slight differences were found. In addition to the common items, two more items were added in 2012: "Read news on the Internet" and "Obtain practical information from the Internet". These two items, although were included as entertainment-related indicators, are more representative of advanced Internet use for information exploration and investigation. Lee and Wu (2013) divided online activities into social entertainment and information seeking, and they suggested when students engage in more online information seeking, they gain a better understanding of how to use metacognitive strategies. Specifically, this type of activity is more goal-oriented and entails more conscious monitoring and evaluation and better self-regulation. In contrast, more purely social online entertainment activities did not possess such characteristics and thus would not produce similar impacts (Lee and Wu, 2013).

Consistent with previous research (Biagi and Loi 2013), Internet use for education purposes at school was found to be a negative influence on student academic performance. In contrast, however, with respect to Internet use for education purposes at home, the current study produced findings that contradicted those from studies, which found that education-related Internet use at home was significantly positively correlated with high academic achievement (Ravitz et, al. 2002). Other researchers, meanwhile, for example Fuchs and Woessmann (2004, cited by Luu and Freeman 2011), had already observed that the relationship between the two variables might not be direct linear, just as with the relationship between time spent on homework and student learning outcomes (Song and Kang 2012; Wittwer and Senkbeil 2008). Although a curvilinear relationship might be a possible explanation, we would like to propose an alternative. By examining all of the items that were measured in both testing cycles, we found that these items only described very common and basic skills that nearly every student possessed. As such, they could not serve as core indicators of higher versus lower achievement. For the current student generation, possessing ICT skills might be less important than how students actually use ICT.

The Influence of ICT Use Confidence on Student Achievement

According to Bandura's theory, self-confidence is a significant predictor for specific tasks. Self-confidence in ICT indicates a personal belief in the capacity to accomplish certain ICT tasks, and it was examined in three PISA testing cycles (2003, 2006, and 2009). Guzeller and Akin (2014) found that students' confidence in performing high-level and Internet-related tasks was associated with higher math scores, which was confirmed by Delen and Bulut (2011). Other researchers found that students who reported higher confidence with high-level ICT tasks had significantly higher levels of scientific literacy (Luu and Freeman 2011; Wittwer and Senkbeil 2008; Sedat, Atalmis, and Erkan 2011). In alignment with previous findings, the current study found a consistently positive relationship between ICT confidence and student achievement in both math and science. Therefore, an important implication of this study is that within the ICT-related education context, confidence in using ICT has more of an effect than frequency of ICT use.

The Influence of the Three Levels of Background Variables

Economic factors from the country, school and student levels were all included in the models and served as the controlling variables. The direct country-level measurement of economic development was national GDP. School-level variables encompassed school economic status, expenditures and income and included average student socio-economic status, school type, quality of school educational resources, and the ratio of web-based instructional computers; individual student socio-economic status was also included. Overall, it was found that both school and student socio-economic levels significantly influenced students' learning outcomes, which was consistent with OECD reports (2006, 2009). Although it has been widely recognized that national GDP is positively influences student achievement (Rindermann 2008), this finding was not supported in this research. Through conducting more exploratory investigation, it was observed that the influence of national GDP was suppressed by the school-level economic factors. Specifically, the original significant positive impacts of country-level GDP were found to be no longer significant when we added the quality of school educational resources and the ratio of web-based instructional computers in each school. To conclude, school-level ICT variables had strong positive impacts on student achievement. Consistent with previous findings (Notten and Kraaykamp 2009), individual student socio-economic status had a positive correlation with academic performance.

Males were consistently found to have better learning outcomes than females in both math and science, which was consistent with previous studies (Gumus and Atalmis 2011; Ong and Lai 2006). According to the PISA 2000 report, males outperformed females in math achievement, which was verified in the subsequent testing rounds. Compared with the large gender differences in math, differences in science tend to be small and complex (Woods-McConney, Oliver, and McConney 2013). This gender gap might be because female students had higher levels of anxiety, less interest in the subjects and less confidence, which all lead to lower achievement (OECD 2007). Given the gap between males and females in math and science, additional support should be provided for females in order to develop their confidence and interest in math and science, such as introducing interactive teaching strategies or improving classroom environments (Liu and Wilson 2009).

IMPLICATIONS FOR FUTURE RESEARCH

A number of implications related to the current analysis have been provided for future studies. First, given the nature of the measurement used in this research, we only intended to explore the association between frequency of ICT use and student

academic performance. Although it is suggested that ICT use might indicate ICT skill levels, we suggest that further research should rely on well-designed instruments that directly assess the range of ICT competencies. The second limitation related to the cross-sectional nature of the datasets used in this research was that we only intended to explore the association between variables, and thus, no causality conclusions should be drawn. The third limitation refers to the selected study sample. With the aim of understanding the trends in the relationship between ICT use and student achievement and to make the results comparable from 2000 to 2012, all countries that participated in the ICT survey were included in the current analysis. However, it is also meaningful to focus on individual countries or regions and to explore how the relationship varied across years or how it was influenced by different national education policies.

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