Computers & Education 125 (2018) 1–13

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

The relationship between ICT and student literacy in mathematics, reading, and science across 44 countries: A multilevel analysis

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ARTICLE INFO

Keywords:
Applications in subject area
Secondary education
Cross-cultural projects

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ABSTRACT

This study conceptualized ICT as multi-level (country-, school-, and student-level) constructs and examined their relationships with student mathematics, reading, and scientific literacy. Three-level hierarchical linear models (HLM) were employed to analyse the Programme for International Student Assessment (PISA) 2015 data of 305,414 15-year-old students from 11,075 schools across 44 countries. The findings indicated that (i) national ICT skills had a more positive effect on student academic performance than did national ICT access and use; (ii) students ICT availability at school positively associated with student academic success, whereas student ICT availability at home negatively associated with student academic success; (iii) student ICT academic use negatively correlated with student performance, while ICT entertainment use positively correlated with student performance; and (v) student attitudes toward ICT demonstrated mixed effects on student academic success – specifically, student interest, competence, and autonomy in using ICT had positive correlations, while student enjoyment of social interaction around ICT had a negative correlation with student academic performance.

ICT Skills

1. Introduction

In the information age, the innovation of education is essential for countries to ensure prosperity and competitiveness and the integration of information and communication technology (ICT) into education has been recognized as key enablers for the educational innovation (Brečko, Kampylis, & Punie, 2014; Pérez-Sanagustín et al., 2017). Therefore, many countries have invested in ICT infrastructures in schools and issued policies regarding the integration of ICT into education, endeavoring to innovate student learning environment (Skryabin, Zhang, Liu, & Zhang, 2015; UIS, 2009). Correspondingly, ICT has been widely used in educational settings. Given the situation, quite a number of studies have been conducted to examine whether ICT advances students' learning (e.g., Cheung & Slavin, 2012, 2013; Erdogdu & Erdogdu, 2015; Harrison et al., 2002; Luu & Freeman, 2011). These studies have unraveled the potential influences of various ICT factors on students' academic performance in different domains.

Despite the substantial efforts in understanding the relationship of ICT and student learning, more research along this line is needed for two reasons. First, previous research has mainly focused on identifying school- (e.g., school ICT availability) and student-level (student ICT use at home) ICT factors that might influence student academic performance (Balanskat, Blamire, & Kefala, 2006; Condie & Munro, 2007; Cox et al., 2003; Zhao & Frank, 2003) without taking into account of nation-level ICT factors. National ICT development level can not only influence school and family ICT richness and educational stakeholders' ICT competence (ITU, 2015; Skryabin et al., 2015), but also act as an important stimulus for educational reforms (Bocconi, Kampylis, & Punie, 2012; Kozma, 2005;

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https://doi.org/10.1016/j.compedu.2018.05.021
Received 26 September 2017; Received in revised form 30 May 2018; Accepted 31 May 2018
Available online 01 June 2018
0360-1315/

OECD, 2017b). However, despite the importance of nation-level ICT factors, little research has been conducted that incorporated the effect of country-level ICT factors into the picture in understanding the impact of ICT on student academic success. Second, the ICT landscape has gone through drastic changes in recent years and it is necessary to constantly monitor the effect of ICT-related factors on student academic performance. According to OECD statistics, among its member countries, the average percentage of households with internet access at home increased from 74% in 2012 to 88% in 2017 (OECD.Stat, 2018). Student access to ICT at schools and homes has also become more convenient due to the increase in national ICT investment and the decline in the prices of ICT facilities (Istance & Kools, 2013). Student computer ratio at schools is also increasing for most countries (especially for developing countries) except those already with almost all students owning computers (OECD, 2015). As ICT may either benefit students' learning or distract students from learning, it remains to be seen whether the increased access to ICT at home and at schools could augment or impede student academic achievement. Furthermore, new and revolutionary ICT products are getting normalized in the education (Johnson et al., 2014). Taking social media for example, as Twitter becomes ubiquitous nowadays, it is also widely used by teachers and students for educational purposes (e.g., communication, collaboration, assessment, and so on) (Tang & Hew, 2017). Thus, the constant changes in ICT landscape make it necessary and important to revisit the relationship of ICT with student learning.

The present study examines the relationship between ICT and student mathematics, reading, and scientific literacy. Specifically, we: (1) conceptualize ICT as multi-level (national-, school-, and student-level) constructs to comprehensively unravel the influential pattern of ICT on student learning attainment; and (2) employ the latest PISA data (PISA 2015 database) encompassing 44 countries to present state-of-the-art evidence about the relation between ICT and student academic performance.

2. Background

2.1. National ICT development and academic achievement

The development of ICT at the national level has a direct influence on education (Hanna, 2003; Heinz, 2016; Skryabin et al., 2015). The United Nations Educational, Scientific and Cultural Organization (UNESCO) proposed a three-level model of ICT integration into educational systems (UIS, 2009). This model comprises the availability of ICT, the depth and breadth of ICT use and the outcomes and effects of ICT use in education. The International Telecommunication Union (ITU) proposed an ICT development index consisting of three factors: ICT access, ICT use and ICT skills (ITU, 2015). These three factors determine the digital divide across and within countries (Ghobadi & Ghobadi, 2013), which might influence students' achievement directly through digital-based learning opportunities and digital competencies and indirectly through social expectations and support for the use of digital technologies for learning (Heinz, 2016; Litt, 2013; Skryabin et al., 2015).

ICT access and use at the national level affects students' access to digital experiences both inside and outside the classroom, which consequently influences learners' ICT skills and their abilities to benefit from the digital-based learning experiences (Hargittai, 2010; Heinz, 2016). Skryabin et al (2015) examined the relationship of national ICT development level to student mathematics, reading, and science performance. They found that national ICT development level had a positive influence on students' achievement in reading, mathematics and science. That is, students from countries with higher ICT levels perform better than those from countries with lower ICT levels. In addition, Skryabin and colleague also examined the potential influence of two more nation-level ICT factors – ICT rate of change and GDP per capita – but found the influence of these variables to be non-significant.

2.2. School-level ICT factors and academic achievement

Schools are at the core of education systems. The ratio of computers to school size has been identified as a potential factor that influences student academic achievement. However, findings on its relationship with student learning have been mixed (Delen & Bulut, 2011; Eickelmann, Gerick, & Koop, 2017). For example, Carrasco and Torrecilla (2012) reported that students from schools with more than 10 computers performed better than those from schools with less than 10 computers in 16 Latin American countries. In contrast, Luu and Freeman (2011) found no correlation between the overall ratio of computers to school size and students' scientific literacy in Australia and Canada. Mixed findings were also reported in the effects of the proportion of school computers connected to the Internet on student academic performance. By analyzing PISA 2000 data, Woessmann and Fuchs (2004) found an inverted U-shape connection existing between Internet use at school and student performance in mathematics and reading. More specifically, students who did not use the Internet at school performed significantly worse in both mathematics and reading than did students reporting medium Internet use at school. However, students with a high frequency of internet use at school performed significantly lower than medium and no use groups. In contrast, Luu and Freeman (2011) reported that Internet connectivity of school computers had no significant impact on the scientific literacy of Canadian PISA 2006 participants but appeared to have a negative relationship with that of Australian ones.

In addition to this ICT-related factor at the school level, some school-level factors not related to ICT (e.g., school size) have also been found to influence the impact of ICT on students' academic performance to a large extent and hence needed to be controlled in the present study even though they were not the main concern in the study (Ma, Ma, & Bradley, 2008). Woessmann and Fuchs (2004) investigated the influence of computer availability on student academic performance based on PISA 2000 data and reported that computer availability at both home and school was positively correlated with student achievement. However, the correlation was no longer significant when controlling for school contextual information and family background. Thus, school size and school location were included as two controlling variables in the present study since previous research has suggested that they influence student learning (e.g., Ma et al., 2008).

2.3. Student-level ICT factors and academic achievement

In contrast to the scant research on ICT-related factors at country and school levels, there have been a substantial number of studies on the relationships of individual-level ICT factors to student academic performance (Eng, 2005; McMahon, Yeo, & Williams, 2011). Student-level ICT factors can be divided into three broad categories: ICT availability, ICT use, and attitudes towards ICT.

Students mainly get access to ICT equipments at home or school. By analysing data of 297,295 students from 42 countries, Lee and Wu (2012) found that ICT availability at home positively affected student engagement in online reading activities but negatively influenced student reading performance, while ICT availability at school had no impact on either engagement in online reading activities or reading performance.

Several factors in relation to students' ICT use have been identified as influencing the effects of ICT on student achievement. One factor is the use of ICT for different subjects and at different grade levels. Research has found that the effect of ICT on student learning outcomes varies across subjects and grades (Bayraktar, 2001; Kulik & Kulik, 1991; Torgerson & Zhu, 2003, pp. 5–16). For instance, in the ImpaCT2 project, ICT has been found to be positively correlated with the science achievement of students at five, eight and ten years. However, its impact on UK student performance in reading has been found to be statistically significant for five-year students but not for either eight-year or ten-year students (Harrison et al., 2002). In their second-order meta-analysis of the impact of ICT on learning, Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011) found that the effective size was larger for K-12 students (0.40) than for postsecondary students (0.29).

Another factor that affects the impact of ICT use on learning is the location of ICT use: at school versus at home. Previous literature has shown that in-class ICT use and home ICT use have different influences on student learning (Skryabin et al., 2015). For instance, Petko, Cantieni, and Prasse (2017) found that school ICT use had a significant negative influence on students' performance consistently in mathematics, reading and science, but the influence of home ICT use showed a different pattern and also varied across the three subjects. Skryabin et al. (2015) further identified that the influence varied across different grade levels. Specifically, they found that both school and home ICT use positively influenced 4th grade students' performance in reading, mathematics and science based on TIMSS 2011 and PIRLS 2011 data; but for 8th grade students, school ICT use had a negative influence, and home use had a positive effect on all three subjects.

A third factor that has been identified as influencing the relationship of ICT use to student learning concerns the different purposes of ICT use: academic use versus entertainment use. Petko et al. (2017) found a positive correlation between student ICT academic use at home and mathematics, science, and reading achievement, but a predominantly negative association between student' ICT leisure use at home and academic performance. However, this finding contradicts the findings of other research studies. In Skryabin and colleagues' (2015) study, home ICT use for both educational purposes and entertainment purposes was found to have a positive influence on 8th graders' mathematics, science and reading performance. Gumus and Atalmis (2011) found that the use of computers for educational purposes showed a negative impact on Turkish students' reading literacy, whereas the use of computers for entertainment purposes had a positive impact.

In terms of the effect of students' attitudes towards ICT, two major factors have been examined so far. One factor is students' interest in ICT. Research studies have shown that students' general interest in ICT has a significant influence on student learning, but the direction of influence is mixed (Lee & Wu, 2012; Papanastasiou, Zembylas, & Vrasidas, 2003). Papanastasiou and colleagues' study of TIMSS 1995 data showed a negative association between students' attitudes towards ICT and student learning, whereas Lee and Wu (2012) study of PISA 2009 reported a positive association. Petko et al. (2017) further found that students' perceptions of the effectiveness of ICT as a learning tool had a predominant significant positive effect on students' performance in mathematics, reading and science, holding demographic characteristics and frequency of ICT use constant. The second student attitudinal factor that influences the impact of ICT on learning is students' self-efficacy of ICT use. Lee and Wu (2012) found that students with greater self-efficacy in ICT are more likely to acquire better reading literacy. Furthermore, in their review article concerning computer self-efficacy, Moos and Azevedo (2009) concluded that student self-efficacy was positively related to learning outcomes in computer-based learning environments.

The current literature suggests that student attitudinal factors have a significant influence on the impact of ICT on learning. However, students' ICT-related attitudinal factors are complex and consist of many constructs (Tsai, Lin, & Tsai, 2001). Most existing research studies have paid attention to only one or two of these constructs (e.g., Petko et al., 2017; Zhao, Lu, Huang, & Wang, 2010). According to OECD (2016), attitudes toward ICT comprise at least the following constructs: student interest in ICT, perceived ICT competence, perceived autonomy in using ICT, and enjoyment of social interaction around ICT. Thus, the present study investigated the influence of attitudes towards ICT in a more comprehensive way by taking all these four attitudinal constructs into account.

2.4. Rationale for the current study and the conceptual framework

The current literature suggests that ICT has an important role to play in education, but its potential impact on student learning is influenced by an array of ICT factors at the national, school, and student levels. By drawing from the previous research, a conceptual framework was devised whereby various ICT factors from national-, school-, and student-levels had potential direct effects on student literacy in mathematics, reading and science (see Fig. 1). At the student level, three broad aspects (i.e., ICT availability, ICT use, and attitudes towards ICT) were considered (e.g., Luu & Freeman, 2011; OECD, 2016; Tsai et al., 2001). Specifically, student ICT availability was categorized into ICT availability at home and at school; student ICT use was elaborated into three indicators (ICT academic use outside of school, ICT leisure use outside of school, and ICT use at school) based on the location and purpose of the ICT use; student attitudes toward ICT was divided into interest in ICT, perceived autonomy in using ICT, perceived ICT competence, and

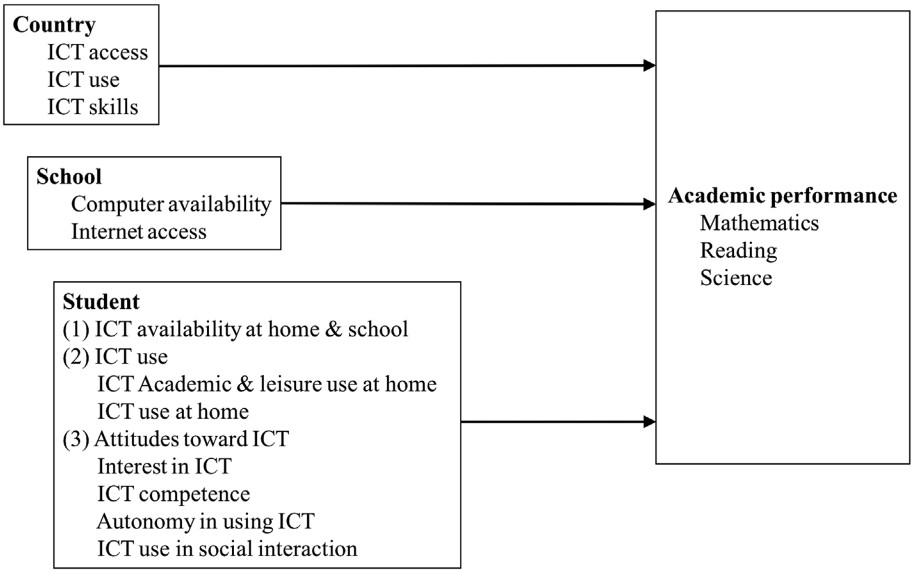

Fig. 1. A conceptual framework of the potential influence of ICT factors on student academic performance.

enjoyment of social interaction around ICT (also see Fig. 1.). In terms of the school-level ICT, school computer availability and Internet connection were considered (Eickelmann et al., 2017); also student-level ICT factors related to school (i.e., student ICT availability at school, ICT use at school, and attitudes toward ICT) were averaged to produce the school mean values, which were used as school-level factors to avoid aggregation bias. Aggregation bias "occurs when a variable takes on different meanings and, therefore, has different effects at different levels of aggregation" (p. 127) (Lee, 2000). For instance, when the impact of student interest in ICT on student learning is examined, the school mean student interest in ICT might work concurrently to influence student learning. Thus, it is critical to take into consideration the related student-level factor at the school level so as to avoid aggregation bias. Since the effect of national ICT development level was confirmed (Skryabin et al., 2015), we went further to consider three more specific factors at the national level national ICT access, use, and skills (ITU, 2015).

To sum up, the conceptual framework addresses the effects of a set of country-, school-, and student-level ICT factors on student academic achievement in the presence of each other so as to generate a more comprehensive understanding of the unique contribution of different ICT-related factors on student mathematics, reading, and scientific literacy. In addition, several variables (i.e., student gender, family socio-economic status, school location, and school size) not shown in Fig. 1 were controlled (Chiu & Chow, 2010; Ma et al., 2008).

3. Method

3.1. Data

The main data source for this study was PISA 2015, an international large-scale assessment that measured 15-year-old students' mathematics, reading, and scientific literacy. A total of 72 countries and regions participated in PISA 2015. The ICT familiarity questionnaire and student background questionnaire completed by students as well as school questionnaire completed by principals were used together to obtain student and school contextual information. Since the ICT familiarity questionnaire was optional for participating countries, only countries that had completed this questionnaire were included. In addition, Puerto Rico (USA) was also excluded from our study because no school information was provided.

Data were also retrieved from the International Communication Union (ITU) and World Bank datasets to generate the national-level indicators. As a member of the United Nations Development Group, the ITU developed the ICT Development Index (IDI), which encompass three indicators (national ICT access, ICT use, and ICT skills) to measure the national ICT development level. In addition, data on national gross domestic product (GDP) per capita was obtained from World Bank datasets. PISA 2015 participating countries and economies that were not involved in the 2015 IDI or GDP per capita survey were excluded in the present study. As a result, a total of 305,414 students from 11,075 schools of 44 countries were retained in the sample (see Appendix A).

3.2. Data analysis

3.2.1. Variables

This study employed student-, school-, and country-level variables based on the proposed conceptual framework for the relationship between ICT and students' academic performance. As mentioned above, student- and school-level variables were from the

Table 1
A summary of student-, school-, and country-level variables.

Gender	Gender
Student-level predictors	
SES	Social-economic status (derived from four indicators; see ESCS in OECD, 2017a)
ICTHOME	Student ICT availability at home
ICTSCH	Student ICT availability at school
HOMESCH	ICT academic use outside of school
ENTUSE	ICT leisure use outside of school
USESCH	ICT use at school
INTICT	Interest in ICT
COMPICT	Perceived ICT competence
AUTICT	Perceived autonomy in using ICT
SOIAICT	Enjoyment of social interaction around ICT
School-level predictors	
SCHSIZE	School size
SCHLOCA	School location (ranging from 1 = fewer than 3000 people to 5 = over 1 million people)
RATCMP1	Ratio of computers to school size
RATCMP2	Proportion of computers connected to the Internet
M_ICTSCH	School mean student ICT availability at school
M_USESCH	School mean student ICT use at school
M_INTICT	School mean student interest in ICT
M_COMPICT	School mean student perceived ICT competence
M_AUTICT	School mean student perceived autonomy in using ICT
M_SOIAIC	School mean student enjoyment of social interaction around ICT
Country-level predictors	
ACCUSE	ICT access & use
SKILLS	ICT skills

PISA 2015 database, while country-level variables were from the ITU and World Bank database.

PISA 2015 mainly assessed students' literacy in mathematics, reading, and science, and all three were employed as dependent variables in the present study. In order to reduce test-learning effects and student fatigue, OECD (2017a) used a balanced incomplete block test design to allocate students subtests of the whole test items and employed the graded response Rasch model to estimate their mathematics, reading, and scientific literacy. Specifically, PISA computed 10 plausible values (PVs) for each student in each of the three subjects to represent a multiple estimation of how the student might have performed if he/she had completed all the test items. All 10 PVs for each subject were taken into consideration simultaneously in the present study as the predicted variables in a single run of an analysis.

At the student level, student gender and family social-economic status (SES) were included as controlling variables. Student-level ICT factors encompassed three main categories – student ICT availability (at home and at school), student ICT use (ICT use at school, ICT academic and leisure use outside school), and attitudes toward ICT (interest in ICT, perceived autonomy in using ICT, perceived ICT competence, and enjoyment of social interaction around ICT).

At the school-level, school location and school size were controlled. Besides, both ratio of computers to school size and proportion of computers connected to the Internet were selected from the PISA school questionnaire. In addition, several student-level ICT factors related to school (i.e., student ICT availability at school, ICT use at school, interest in ICT, perceived ICT competence, perceived autonomy in using ICT, enjoyment of social interaction around ICT) were aggregated by averaging the predictors for each school in order to derive school-level indicators (see Table 1).

At the country-level, log GDP per capita was considered to be controlled. Country-level ICT factors contained national ICT access, ICT use, and ICT skills. ICT access encompasses five indicators: fixed-telephone subscriptions, mobile-cellular telephone subscriptions, international Internet bandwidth per user, households with computers, and households with Internet access; ICT use encompasses three indicators: internet users, fixed (wired)-broadband subscriptions, and wireless broadband subscriptions; and ICT skills encompasses three indicators: adult literacy, gross secondary enrolment and gross tertiary enrolment (ITU, 2015).

Since so many variables were included in the study, special attention was paid to avoiding multicollinearity. First, a correlation matrix was computed between the predictors. Caution should be exercised when correlation coefficients exceed 0.80 (Field, 2009). Second, the variance inflation factor (VIF) was employed, whereby any VIF exceeding 10 should be considered as a multicollinearity problem (Stevens, 2012). The analysis indicated that none of the VIFs exceeded 10 in the study. However, some predictors were strongly correlated with each other at the country-level: log GDP per capita was strongly correlated with ICT access (.86) and ICT use (0.84); while ICT access was strongly correlated with ICT use (0.90). To address the issue, log GDP per capita was first excluded from the analysis; then ICT access and ICT use were combined to create a new index: ICT access and use. Since the ITU gave ICT access and ICT use the same weight (.40) when producing the IDI (ITU, 2015), ICT access and ICT use were averaged to create the new index – ICT access & use. None of the other correlations exceeded 0.60. The summary of all student-, school-, and country-level predictors are listed in Table 1. Expectation maximization (EM) was employed to impute missing data at the student- and school-level.

3.2.2. Hierarchical linear modelling (HLM)

Since students are clustered at schools and schools are nested at countries, multiple regression cannot be employed; rather, it should be used to model effects at the same level. Three-level hierarchical linear modelling was employed to build models because it takes the nested nature of the data into consideration and can avoid statistical and interpretational problems (Goldstein, 2011; Hox, 2010). As a mass of variables from country-, school-, and student-levels were considered in the study, predictors at the student- and school-levels were centred on the grand mean to reduce multicollinearity among the predictors further (Tabachnik & Fidell, 2007).

As used in the previous study (Luu & Freeman, 2011), step-be-step exploratory model building strategy (Hox, 2010) was employed to build models with the variables of interest for each subject. All the models had the same meaning and structure for mathematics, reading, and science, and the data analysis procedure was reported altogether.

First, a one-way ANOVA model with random effects (null model) was built to test if the variances were significant at each level:

$$Y_{ijk} = \gamma_{000} + e_{ijk} + r_{0jk} + u_{00k}$$

Where

Y_{ijk} is the mathematics/reading/science scores for the student i in school j in country k
γ_{000} is the grand mean mathematics/reading/science scores for all countries included in the sample
e_{ijk} is the residues for student i in school j of country k
r_{0jk} is the residues for school j in country k
u_{00k} is the residues for country k.

Second, explanatory predictors were included in sequential sets: the first set was **U** student-level variables (GENDER, SES, ICTHOME, ICTSCH, HOMESCH, ENTUSE, USESCH, INTICT, COMPICT, AUTICT, SOIAICT). Each student-level predictor was included separately in the null model to test its absolute effect; predictors with significant effects ($p < .05$) were then added together to test their effects in the presence of other predictors (Luu & Freeman, 2011; Ma et al., 2008). If any predictor became no longer statistically significant in the model, the predictor with the largest p-value was removed. This step was repeated until all included predictors were statistically significant with the dependent variable. Then, each of the **V** school-level variables (SCHSIZE, SCHLOCA, RATCMP1, RATCMP2, M_ICTSCH, M_USESCH, M_INTICT, M_COMPICT, M_AUTICT, M_SOIAIC) was added to the model built above, followed by the inclusion of all statistically significant variables. One variable with the largest p-value at one time was still excluded until all remaining variables were statistically significant. Last, the procedure for **V** was employed for **W** country-level variables (ACCUSE and SKILLS) to produce the final model.

$$Y_{ijk} = \gamma_{000} + \pi_{ujk}\,\mathbf{Student}_{ijk} + \beta_{0vk}\,\mathbf{School}_{0jk} + \gamma_{00w}\,\mathbf{Country}_{00k} + e_{ijk} + r_{0jk} + u_{00k}$$

Where

π_{ujk} is the slope of U student-level variables for student u in school j of country k
β_{0vk} is the slope of V school-level variables for school v in country k
γ_{00w} is the slope of W country-level variables for country w.

4. Results

The results of the null models showed that country-, school-, and student-level variance in mathematics literacy were 30.54%, 27.00%, and 42.46% respectively (see Table 2); country-, school-, and student-level variance in reading literacy were 21.18%, 31.46%, 47.36% respectively; and country-, school-, and student-level variance in scientific literacy were 24.96%, 29.50%, and 45.54% respectively. Since school- and country-level variances accounted for a considerable proportion of the total variance in literacy in all three subjects, further analysis with HLM was essential to explore the effects of predictors from different levels.

In the following sections, the relationships between country-, school-, and student-level predictors of interest and student academic performance are introduced. Only the final models (random intercept full model with statically significant predictors from all the three levels) are described in the present study. Ancillary statistical tests and regression models are available upon request from the authors. Since the controlling variables were not the main concern in the present study, they were only shown in Table 3, and not reported in the result and discussion parts.

Table 2
Country-, school-, and student-level variance of mathematics, reading, and scientific literacy.

	Mathematics (Percentage)	Reading (Percentage)	Science (Percentage)
Country	3346.66 (30.54)	2427.73 (21.18)	2574.31 (24.96)
School	2958.92 (27.00)	3605.82 (31.46)	3043.46 (29.50)
Student	4652.93 (42.46)	5428.22 (47.36)	4697.34 (45.54)

Table 3
Final Hierarchical Linear Models predicting Mathematics, Reading, and Scientific Literacy.

	Mathematics		Reading		Science	
Fixed Effect	Gamma (SE)	*t*	Gamma (SE)	*t*	Gamma (SE)	*t*
INTRCPT	469.02 (7.23)	64.912**	471.56 (7.20)	65.53**	470.01 (6.29)	74.73**
Level-3 Predictors						
ACCUSE						
SKILLS	39.71 (9.92)	4.00**	29.19 (9.66)	3.02**	30.99 (8.90)	3.48**
Level-2 Predictors						
SCHSIZE	0.02 (0.01)	3.21**	0.02 (0.01)	2.60**	0.02 (0.00)	4.20**
SCHLOCA			5.80 (2.17)	2.67**		
RATCMP1						
RATCMP2						
M_ICTSCH	4.93 (1.44)	3.42**	5.29 (1.41)	3.74**	5.33 (1.33)	4.00**
M_USESCH	−9.26 (4.11)	−2.25*	−11.72 (4.36)	−2.69**	−11.29 (3.76)	−3.00**
M_INTICT	30.87 (6.23)	4.96**	32.78 (7.37)	4.45**	29.81 (7.09)	4.20**
M_COMPICT						
M_AUTICT	21.53 (6.75)	3.19**	25.80 (7.69)	3.35**	29.15 (6.77)	4.30**
M_SOIAIC	−30.98 (9.81)	−3.16**	−32.80 (10.91)	−3.01**	−32.13 (10.19)	−3.15**
Level-1 Predictors						
GENDER	10.89 (1.96)	5.55**	−19.95 (1.56)	−12.82**	5.70 (1.21)	4.70**
SES	12.91 (1.39)	9.31**	12.11 (1.83)	6.64**	12.62 (1.71)	7.37**
ICTHOME	−2.38 (0.45)	−5.32**	−2.40 (0.42)	−5.67**	−2.69 (0.33)	−8.04**
ICTSCH						
HOMESCH			−4.50 (0.87)	−5.21**	−5.35 (0.65)	−8.24**
ENTUSE			3.21 (1.44)	2.24*	3.33 (1.08)	3.07**
USESCH	−9.67 (0.96)	−10.02**	−12.56 (1.60)	−7.87**	−10.52 (0.96)	−11.01**
INTICT	4.16 (0.99)	4.19**	7.88 (0.91)	8.69**	5.08 (0.79)	6.46**
COMPICT	2.83 (1.00)	2.82**	3.36 (1.02)	3.30**	3.11 (0.79)	3.95**
AUTICT	5.35 (1.52)	3.51**	5.61 (1.72)	3.26**	7.41 (1.61)	4.61**
SOIAICT	−2.65 (1.12)	−2.37*	−4.27 (1.31)	−3.27**	−3.61 (1.20)	−3.00**
Random effects	**Variance**	**S.E.**	**Variance**	**S.E.**	**Variance**	**S.E.**
Level-3 effect	1129.42	33.61	797.05	28.23	854.60	29.23
Level-2 effect	2132.14	46.18	2340.58	48.38	2094.23	45.76
Level-1 effect	4419.67	66.48	5039.45	70.99	4403.34	66.36

4.1. Country-level ICT factors

Results showed that students living in countries with more advanced ICT skills tended to perform better than their counterparts in all three subjects after controlling for all the other predictors (from each level). On average, a one score increment in country ICT skills raised students' mathematics, reading, and science scores by 39.71, 29.19, and 30.99, respectively. In contrast, the relationship between country ICT access and use and student achievement was not statistically significant for all three subjects after controlling for the other predictors.

4.2. School-level ICT factors

Neither ratio of computers to school size nor proportion of computers connected to the Internet had any significant effect on literacy in all three subjects. Meanwhile, school mean student ICT availability at school positively affected students' performance: with a one score increment in the school mean ICT availability, students' literacy in the three subjects increased by about 5 scores. In contrast, school mean student ICT use at school negatively correlated with students' performance: students scored 9.26, 11.72, 11.29 points lower in mathematics, reading, and scientific literacy respectively per score increase in school mean ICT use.

In terms of school mean ICT attitudes, both school mean student interest in ICT and perceived autonomy in using ICT had positive correlations with student literacy in all the subjects, while the correlations between student enjoyment of social interaction around ICT and their mathematics, reading, and science scores were negative. The impact of school mean student perceived ICT competence on student performance was insignificant in all three subjects. An increase in the school mean student interest in ICT of one score raised students' mathematics, reading, and scientific literacy by 30.87, 32.78, and 29.81 scores respectively. Similarly, students averaged 21.53, 25.80, and 229.15 scores higher in mathematics, reading, and science scores respectively with an increase of one score in the school mean student perceived autonomy in using ICT. With a one score increasement in the school mean student enjoyment of social interaction around ICT, students' mathematics, reading, and science scores decreased by 30.98, 32.80, and 32.12 respectively.

4.3. Student-level ICT factors

Student ICT availability at home was found to have negative correlations with student academic achievement: with a one score increment in family ICT availability, students' scores in mathematics, reading and science decreased by an average of 2.38, 2.40, 2.69 respectively. Student ICT availability at school, meanwhile, had no influence on students' performance. In terms of ICT usage, student ICT use at school had negative correlations with their performance: a one score increment in their ICT use at school reduced students' mathematics, reading, and science scores by 9.67, 12.56, and 10.52 respectively. Regarding student attitudes toward ICT, some interesting variation of the effects of ICT home use across subjects was found. Specifically, ICT academic use outside school also had negative correlations with students' reading and scientific literacy: with an increase of one score in ICT academic use outside school, reading and science scores decreased by 4.50 and 5.35 respectively. Instead, ICT leisure use outside school was positively associated with students' performances: students averaged about 3 points higher in both reading and scientific literacy with a one score increase in their ICT leisure use outside school. Neither ICT academic use nor leisure use outside school had any effects on students' mathematics literacy.

Furthermore, all included attitudinal predictors had significant associations with students' academic performance: interest in ICT, ICT competence and autonomy in using ICT were found to have positive correlations, whereas student enjoyment of social interaction around ICT was found having a negative correlation. With a one score increment in students' interest in ICT, their literacy in mathematics, reading, and science increased by 4.16, 7.88, and 5.08 scores respectively. Similarly, students averaged around 3 and 6 scores higher in all subjects with a one-score increment in their perceived ICT competence and autonomy in using ICT respectively. Conversely, a one-score increment in student enjoyment of social interaction around ICT reduced students' mathematics, reading, and scientific literacy scores by 2.65, 4.27, and 3.61 respectively.

Altogether, the included predictors in the present study explained 66% of the variance among countries, 28% of the variance among schools, and 7% of the variance among students for mathematics literacy. Similarly, the explained variances among countries, schools, and students were 69%, 35%, and 7% respectively for reading literacy, while those for scientific literacy were 67%, 31%, and 6% respectively. As can be seen, the explained variances at each level also show similar patterns among these three subjects. Altogether, the included predictors accounted for 30, 29, and 29 of the total variances for mathematics, reading, and science achievement respectively.

5. Discussion

In this study, we examine the relationship between national-, school-, and student-level ICT factors and student mathematics, reading, and scientific literacy. The results indicated that ICT explained considerable variance in student academic performance (especially at the national- and school-levels); besides, different ICT factors showed diverse influential patterns on student learning outcomes. The effects of each country-, school-, and student-level ICT indicator on student academic performance are discussed below, followed by reflection on the design of the PISA ICT familiarity questionnaire and the related secondary analysis.

5.1. Country-level ICT and student performance

In terms of the relationships between national ICT development level and student academic achievement, the results concurred with Skryabin et al. (2015) findings in that national ICT level had a positive impact on student academic performance. Nevertheless, we went further to reveal the unique effects of two more specific aspects of national ICT development level: national ICT skills and ICT access and use. The effect of national ICT skills on student literacy in mathematics, reading, and science was positive after controlling for national ICT access and use, which suggests that students from countries with higher overall levels of ICT skills are more likely to have better outcomes. On the contrary, national ICT access and use were found not to correlate with student mathematics, reading, and scientific literacy after controlling for national ICT skills.

One reason might be the easy accessibility of ICT nowadays. With the decline in the prices of ICT facilities and the increase in national ICT investment, students can easily have access to and use ICT facilities in their learning and daily lives across the world (Luu & Freeman, 2011). Given the situation, the integration of ICT into education might be determined by "the foundation skills required in a digital environment" (OECD, 2015, p. 15) rather than the ICT richness. As a result, national ICT skills matter more in determining whether students could benefit from their ICT experiences than national ICT access and use does. This finding concurs with Ghobadi and Ghobadi (2013) argument that ICT skills are what matters in shaping the digital divide in developed countries. Therefore, policy makers and educators should put more emphasis on improving students' and adults' ICT skills. To achieve this, ICT education at K-12 and even undergraduate level should be re-evaluated and highlighted more. It is worth noting that the finding might be biased by the fact that the sample countries in the study were predominantly developed countries, where the ICT penetration rate is quite high. It is possible that national ICT access and use might have more significant influences on student learning in less developed countries. Thus, more research is needed to explore the landscape in developing countries uninvolved in the present research.

5.2. School-level ICT and student performance

The relationships of ratio of computers to school size and proportion of computers connected to the Internet are discussed below, while the school mean student ICT factors are discussed in the next section, along with their corresponding student ICT factors, to provide a clearer picture.

It was found that the ratio of computers to school size had no significant impact on student mathematics, reading and scientific literacy. This was consistent with Delen and Bulut (2011) finding, which suggested that ICT usage at school was a weak predictor of mathematics and science achievement. A possible explanation of the result is that the school-level indicator of ICT availability measured by means of ratios can lead to little variability regardless of school size (Luu & Freeman, 2011).

Similarly, the proportion of computers connected to the Internet was not significantly related to student mathematics, reading and scientific literacy. The finding was in accordance with Luu and Freeman (2011) result in Canada, but contradicted their finding in Australian, where a negative connection between computer connectivity to the Internet with science literacy was found. The finding also differed from the result reported in Woessmann and Fuchs (2004) study, which demonstrated an inverted-U relationship existing between Internet connectivity at school and student mathematics and reading performance. It might be because schools and teachers in general do not provide students with the opportunites to engage in Internet-related activities, or that students do not use the Internet for learning purposes.

5.3. Student-level ICT and student performance

5.3.1. ICT availability

ICT availability at home was found to be negatively correlated with mathematics, reading and science achievement, which aligns with previous research (e.g., Lee & Wu, 2012). One possible reason behind this negative association might have something to do with the quality of student ICT use at home. It might be possible that easy and unmonitored access to ICT at home might have boosted the negative psychological and social effects of ICT, such as addiction to computer game playing (Grüsser, Thalemann, & Griffiths, 2006) or browsing indecent content like pornography (Wolak, Finkelhor, Mitchell, & Ybarra, 2008). Hence, it is essential for parents or guardians to monitor student's use of ICT facilities at home carefully and guide them to use online resources for both educational and entertainment purposes appropriately (Lee & Wu, 2012; McMenemy & Burton, 2005).

Student ICT availability at school was found to have no correlations with student mathematics, reading, and scientific literacy, which is consistent with the results of two school variables discussed above (ratio of computers to school size and proportion of computers connected to the Internet). However, school mean student ICT availability at school positively correlated with student literacy in all three subjects. The findings indicated that school ICT availability mattered in shaping student academic, although not at the individual level. Given the different influential patterns of student ICT availability at school and school mean student ICT availability at school, we urge scholars to be cautious about aggregation bias when analyzing multilevel data (Lee, 2000).

5.3.2. ICT use

The study found that student ICT use at school had negative correlations with students' mathematics, reading and scientific literacy, which was also the case for school mean student ICT use at school. The result was in agreement with previous studies (e.g., Petko et al., 2017). Skryabin et al. (2015) found that ICT usage at school 'may not have a strong direct association with learning outcomes' (p. 56) since very narrow learning areas are affected by specific computer programs. Given that teachers in general have been found to use technologies for a narrow set of pedagogical purposes without changing their existent ways of teaching (Ertmer & Ottenbreit-Leftwich, 2010, 2013; Hew & Brush, 2007), a higher frequency of ICT use at school may not benefit students' learning and may even be detrimental to student learning.

Similarly, ICT academic use outside school showed negative correlations with students' reading and science achievement but had no significant effect on mathematics achievement. This result was consistent with some of the previous studies (e.g., Carrasco & Torrecilla, 2012; Gumus & Atalmis, 2011) but contradicted other ones (e.g., Petko et al., 2017; Skryabin et al., 2015). One possible reason for the mixed results might be the broad nature of the construct and the different ways ICT use was operationalized in previous studies. ICT can be used for learning in a variety of venues outside school. For example, Carrasco and Torrecilla (2012) selected 5 alternatives to represent student ICT use at school, while Petko et al. (2017) employed 9 alternatives to represent the same construct. Some approaches might have positive effects on student learning, while others work in a contrary direction. Consequently, the effect of ICT academic use outside school becomes inconclusive when different studies employ different ICT activities to produce the overall indicator of ICT use activities at school.

While the basic aim of integrating ICT into education is to facilitate student learning, the negative relationship between either student ICT academic use at school or outside school and their learning outcomes deserve serious attention. The results might indicate that ICT was not used in a satisfactory approach to enhance student learning; in contrast, the frequent ICT use even had negative effects on student learning. While the effectiveness of educational technology (e.g. technology-based curricula, computer-assisted instruction, and integrated learning systems) on student academic performance has been confirmed in the previous literature (Bayraktar, 2001; Cheung & Slavin, 2012, 2013; Kulik & Kulik, 1991; Torgerson & Zhu, 2003, pp. 5–16), principals and teachers should consider employing these educational technologies to improve the educational power of ICT use. However, it is worth noting that the relationship between ICT use and student academic literacy could also be reverse given the cross-sectional nature of the study. Eickelmann et al. (2017) proposed that the negative correlation might be because low achievers use ICT more frequently to make up for their low achievement. If this is the case, educators should also adopt more effective educational technology to make more students (both high and low achieving students) be benefited from the ICT integration into education. Therefore, on the one hand, more follow-up studies (e.g., interview or experimental study) are needed to determine the casual-and-effect relationship. On the other hand, effective educational technology should be implemented to enhance the educational function of ICT use for all students. Furthermore, we argued that more attention should be paid to the design of ICT academic use in the ICT Familiarity Questionnaire. Some limitations of the current questionnaire were discussed in the section of 'Reflection on PISA ICT Familiarity Questionnaire' below.

ICT leisure use outside school was positively associated with reading and scientific literacy but had no significant correlations with mathematics literacy. The positive impact of ICT leisure use outside school on reading literacy was in line with existing research (e.g., Gumus & Atalmis, 2011; Skryabin et al., 2015), while the influences on mathematics and scientific literacy were different from those in Skryabin et al. (2015). By using data from 39 countries in the PISA 2012 database, Skryabin et al. (2015) found that ICT leisure use demonstrated negative effects on student mathematics literacy but was not associated with scientific literacy. Since the present study employed the data of 44 participating countries in the PISA 2015 database, this inconsistency showed the trends of relationship between student academic performance and ICT leisure use outside school. From 2011 to 2015, the impact of ICT leisure use on student mathematics and scientific literacy changed from negative to neutral and from neutral to positive respectively. In general, students benefit more from ICT leisure use outside school in terms of their academic performances. In the 21st century, ICT seems to have become ubiquitous and multi-functional, and students have engaged themselves more and more in ICT usage. In particular, ICT facilities play not only educational but also entertainment roles among students, such as playing games, online chatting, listening to music and watching movies (Cheema & Zhang, 2013). Apart from assisting learning, other functions of ICT may increase students' motivation and help them to develop their skills on the one hand, and also distract students from their learning in the classroom and prevent them for spending enough time for doing their homework and reading various materials on the other.

Since the relationships between both ICT academic use outside school and ICT entertainment use outside school and student academic performance were different for different subjects (mathematics, reading, and science), this finding might have something to do with the nature of the subjects. Taking reading as an example, on the one hand, out-of-class exposure to the language leads to greater reading comprehension abilities (Larsson, 2012; Sundqvist & Wikström, 2015), and exposure to entertainment sources in the language creates the ideal condition for free voluntary reading (Krashen, 2011). Thus, ICT leisure use outside school has positive influences on reading. On the other hand, the frequency of ICT use in carrying out school-related reading assignments might take away students' opportunities for free voluntary reading, which in turn may negatively affect their reading development. Since little research has been conducted on the interaction between ICT use outside school and the nature of the subjects, especially in the cases of mathematics (Authors, 2006) and science (Osborne & Hennessy, 2003), further studies are needed to determine the relationships between subject-related ICT use outside school and student academic performance, and how the relations may differ across subjects.

5.3.3. Attitudes toward ICT

In terms of attitudinal variables of ICT usage, students who reported higher interest, autonomy and competence in ICT presented significantly higher performance in mathematics, reading and science. The aggregation effects of school mean student interest in ICT and perceived autonomy in using ICT also showed positive correlations with mathematics, reading, and scientific literacy; whereas the effect of school mean student perceived ICT competence was insignificant. These positive relationships were congruent with previous studies (e.g., Lee & Wu, 2012; Petko et al., 2017). Conversely, both student enjoyment of social interaction around ICT and its aggregation effect at the school level (i.e., school mean student enjoyment of social interaction around ICT) negatively correlated with student mathematics, reading, and scientific literacy. In general, students' interest, competence, and autonomy in using ICT had different degrees of positive associations with their academic performance, while their enjoyment of social interaction around ICT had negative associations with academic performance. Given the different influential patterns of each attitudinal factor, the results indicated the necessity to employ multidimensional constructs of ICT attitudes to explore their respective effects on student learning. Moreover, it still remains unclear how these attitudes toward ICT influence student learning outcomes, and further research to reveal the mechanism is needed.

5.4. Reflection on PISA ICT familiarity questionnaire

Investigating the relationship between student academic performance and ICT-related factors by using PISA Familiarity Questionnaire provides a grand and meaningful understanding for the field, as shown in the present study. However, it also has some limitations and some improvement needs to be considered. First, the questionnaire failed to capture the quality of students' ICT use, which has been proven to be crucial predictors in exploring the relationship between student ICT use and their learning outcomes (Lei, 2010). Student ICT use at school contained 9 items (e.g. 'Chatting online at school', 'Using email at school', and 'Using school computers for group work and communication with other students'), and student ICT use outside school contained 12 items (e.g., 'Browsing the Internet for schoolwork', 'Checking the school's website for announcements', and 'Downloading science learning apps on a mobile device'). As can be seen, both of the two sets of items mainly focused on the frequencies or quantities of various ICT use and did not take the quality of ICT use into consideration. However, Lei and Zhao (2007) found that the quantity of ICT use can advance student learning only when the quality of ICT use is ensured. Without taking the quality of the ICT use into account, the PISA ICT Familiarity Questionnaire may have lost the power to capture the exact influence of ICT academic use on student academic performance. Therefore, we argued that some items regarding the quality of ICT use should be considered and designed in the PISA ICT Familiarity Questionnaire.

Second, some existing items for ICT use in the questionnaire (i.e., ICT use at school and ICT academic and leisure use outside of school) need to be refined. Taking one item ('Downloading learning apps on a mobile device') in the construct of ICT academic use outside school for example, if one student downloads only one app within one year and uses it everyday, and another student downloads learning apps frequently but seldom uses them, the item may fail to indicate the exact frequency of students' ICT use.

Third, students' specific ICT usage for each subject (mathematics, reading, or science) need to be included to allow more fine-tuned discussions on the effective ICT use for each subject (To reduce students' workload in completing the questionnaire, each round of the PISA test could include the survey of subject-specific ICT use for the main subject only).

Moreover, researchers should always be cautious about interpreting results of secondary analysis of PISA ICT Familiarity

Questionnaire. Generally, two lines of research have been employed to explore the relationship between ICT and student learning outcome: survey studies (Skryabin et al., 2015) and experimental studies (Cheung & Slavin, 2012, 2013). Comparing to the experimental study, the survey is generally beneficial to involve more participants, understand what happens in the natural settings, and collect richer information on ICT (e.g., national- and school-level ICT factors). However, only correlations between variables can be drawn from survey studies due to the cross-sectional nature of the data. Therefore, scholars should either interpret the relationship as correlational or conduct follow-up study (experimental study or interview) to determine the cause-and-effect relationships after the survey study.

6. Conclusion

The present study mainly contributes to the field by: (1) offering a conceptual framework regarding the influence of ICT factors from national-, school-, and student-levels on student learning outcomes based on the previous literature; (2) examining the relationship between the proposed ICT factors and student mathematics, reading, and scientific literacy using the latest PISA data across 44 nations; and (3) reflecting the design of the PISA ICT Familiarity Questionnaire and the secondary analysis using the questionnaire. The results indicated that most ICT-related factors significantly influenced student learning outcomes, and some of them were negative influences. Therefore, on the one hand, ICT needs to be integrated into education since it may be a possible solution to some puzzling educational problems; on the other hand, ICT should be employed carefully in educational settings, and further action to improve the quality of ICT integration into education (e.g. the application of effective educational technology like technology-based curricula, computer-assisted instruction, and integrated learning systems) is essential.

The study has a few limitations. Firstly, more sophisticated factors with respect to student ICT use should be used to explore their effects on student learning since the student ICT use factors included in the present study did not perform well in predicting student academic performance. As Lei and Zhao (2007) argued, the quantity of ICT use can advance student learning only when the quality of ICT use is ensured. Therefore, more factors related to the quality of student ICT use should be considered in order to determine their influences on student learning outcomes and their interaction with the quantity of student ICT use. Secondly, teacher ICT-related factors should be considered in order to examine their impact on student learning outcomes. Because PISA did not include teacher ICT factors in the contextual questionnaire, their influences on student learning achievement could not be examined in the present study. However, based on previous studies (Bingimlas, 2009; Pelgrum, 2001), teachers did play an important role in the successful integration of ICT in teaching and learning. Therefore, further research can examine the effects of teachers' ICT-related factors on student academic performance. Thirdly, sample bias may have existed in the present study since the PISA data consisted primarily of student data from the more developed countries, and less developing countries (especially African countries) were included. Therefore, the findings need to be treated with caution in explaining the situation in countries excluded from this study. Last but not the least, student learning takes place in the organic interaction among the various components of the holistic learning environment, where ICT is a critical but one piece of the puzzle (Johnson et al., 2014). Thus, ICT interacts with other aspects of learning environment to influence student learning by affecting almost all the aspects of learning environment (Brečko et al., 2014; Law, Yuen, & Fox, 2011; OECD, 2017b). The present study singled out the ICT factors without considering those intricate interactions. This approach allowed a large-scale statistical modelling and testing of how ICT factors at multiple levels interact with one another to influence student learning in different subject domains. However, the complexity of the interaction of ICT factors and other learning factors were left unaccounted for. Thus, more fine-tuned research is needed to consider the role of ICT in the wide context of learning environment, that is, to explore how ICT might interact with other aspects of learning environment (e.g., content & curricula, teaching practices, or assessment; Bocconi et al., 2012) to finally impact student learning attainment.

Appendix A. Sample of the study

Country	Number of Schools	Number of Students
Australia	758	14530
Austria	269	7007
Belgium	288	9651
Brazil	841	23141
Bulgaria	180	5928
Chile	227	7053
Colombia	372	11795
Costa Rica	205	6866
Croatia	160	5809
Czech Republic	344	6894
Denmark	333	7161
Dominican Republic	194	4740
Estonia	206	5587
Finland	168	5882
France	252	6108

Germany	256	6504
Greece	211	5532
Hong Kong	138	5359
Hungary	245	5658
Iceland	124	3371
Ireland	167	5741
Israel	173	6598
Italy	474	11583
Japan	198	6647
Korea	168	5581
Latvia	250	4869
Lithuania	311	6525
Luxembourg	44	5299
Macao	45	4476
Mexico	275	7568
Netherlands	187	5385
New Zealand	183	4520
Peru	281	6971
Poland	169	4478
Portugal	246	7325
Russian Federation	210	6036
Singapore	177	6115
Slovak Republic	290	6350
Slovenia	333	6406
Spain	201	6736
Sweden	202	5458
Switzerland	227	5860
Thailand	273	8249
Uruguay	220	6062
Total	11075	305414

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