Does ICT Matter? Unfolding the Complex Multilevel Structural Relationship between Technology Use and Academic Achievements in PISA 2015

Sandy C. Li[1*] and Karen B. Petersen[2]
[1]Hong Kong Baptist University, HKSAR, PRC // [2]Aarhus University, Denmark // sandyli@hkbu.edu.hk // kp@edu.au.dk
[*]Corresponding author

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ABSTRACT: While infusion of technology into schools has been one of the top priorities of the education reform agenda across the world, findings from many large-scale international assessments indicate that students' use of information and communication technology (ICT) has mixed effects on their academic achievements. In this paper, we argue that these ambivalent findings were due to the oversight of the indirect effects of ICT use mediated by other ICT-related variables. We employed multilevel structural equation modelling to unfold the relationship between students' ICT use and their academic achievements based on PISA 2015 data. The results indicated that students' autonomy in ICT use and students' interest in ICT use were found to have significant positive direct effects on students' academic achievements at both within-school and between-school levels. These two variables played a significant role in mediating the indirect effects of ICT use outside school for schoolwork and ICT resources on students' academic achievements. On the contrary, ICT resources and ICT use at school exerted either no direct effect or a negative direct effect on students' academic achievements and students' perceived autonomy related to ICT use, suggesting that mere provision and use of ICT resources in school did not necessarily guarantee success in student performance. At the school level, school's transformational leadership and collaborative climate helped promote students' autonomy in ICT use.

Keywords: ICT use, Academic achievement, Multilevel analysis, Structural equation modelling, PISA 2015

1. Introduction

Students of today's generation have been immersed in tablets, smartphones and different forms of digital media from a very early age. The rapid advent of information and communication technologies (ICT) in the past two decades has disrupted the world in the ways that people live and interact with one another. ICT is so pervasive that it has become an integral part of our daily-life and one of the key vehicles for driving economic development and leveraging academic attainments. Harnessing new technologies are considered pivotal to education quality, equality, inclusion and life-long learning for all. It is anticipated that the use of ICT helps connect learning across formal and informal contexts in a seamless way (Cai et al., 2019). As such, this global phenomenon has spawned a proliferation of research studies on ICT implementation in schools in the past two decades (Bernacki et al., 2020; Sanders & George, 2017). Nonetheless, the impact of ICT use on students' academic achievements has been equivocal. Large-scale studies on technology integration and student achievements, such as SITES, TIMSS, PISA and PIRLS, have yielded ambivalent results (Bulut & Cutumisu, 2018). The scoping literature review of research articles on PISA assessment published over the past 10 years conducted by Odell et al. (2020) revealed that the relationship between ICT use and academic achievements is ambivalent, and that the relationship varies across subjects, countries and the types of ICT use.

As pointed out by Park and Weng (2020), the statistical methods employed in many large-scale international assessment studies, such as PISA, were mainly hierarchical linear modelling (HLM). To analyze the relationship between the predictors and the multivariate outcome variables such as the mathematics, reading and science scores, a series of HLM analyses have to be conducted separately, which can inflate Type I error. Furthermore, although the abovementioned studies adopted a multi-level approach to data analysis, many of them emphasized on examining how country-level ICT factors, such as GDP per capita and National ICT development index (Hu et al., 2018; Odell et al., 2020; Park & Weng, 2020), impacted on academic achievements without considering the effects of school-level factors, such as school leadership and school climate, which are deemed to be conducive to ICT implementation in school. In addition, at the student-level, none of the above studies examined how the mediation among ICT-related variables actually affected academic achievements. For instance, the provision of ICT resources may not have a direct effect on academic achievements, but it can have a direct effect on promoting students' attitude and autonomy in ICT use, which in turn may have a positive impact on student learning. Yet, HLM is not adequate enough for unfolding these mediation and indirect effects. As such, the

inconsistency in results on the relationship between ICT-related variables and academic achievements can be attributed to the methodological inadequacy in data analysis, and the lack of an ecological perspective in examining how the interplay of ICT-related variables and school-level variables actually affected students' academic achievements.

To shed more light on the ongoing controversy over the effect of students' ICT use on their academic achievements, it is necessary to develop an analytical framework that can delineate the complex interplay of various ICT-related variables in mediating the relationship between ICT use and academic achievements within and across different levels.

2. Conceptual framework

ICT implementation in school has long been seen as a complex process. According to the ecological perspective of ICT implementation suggested by Wong and Li (2011), and Li and Choi (2014), the impact of ICT on student learning and academic achievements hinges on a wide spectrum of variables such as student-level, teacher-level and school-level variables. These include students' ICT access, students' competency in ICT use, students' attitude towards ICT use, students' autonomy in ICT use, teacher's collaboration and school leadership. The subtle within-level and cross-level interactions among these variables play a significant role in mediating the relationship between ICT use and students' academic achievements. Ignoring the ecological dynamics of these variables in ICT implementation might lead to significant discrepancies in the results. This is seen as one of the possible reasons accounting for the ambivalent findings regarding the relationship between ICT use and students' academic achievements found in many large-scale international assessment studies (Park & Weng, 2020).

In the context of large-scale international assessments such as PISA, it remains unknown about the within- and between-level interactions among ICT-related variables mediate the relationship of ICT use and students' academic achievements. To bridge these gaps, the purpose of the present study was to unfold the complex relationship between ICT use and students' academic achievements by constructing multilevel structural equation models in which variables can interact with one another along multiple paths and across different levels. Guided by the ecological perspective of ICT implementation mentioned above, we specifically examined (1) the direct effects of various ICT-related variables on academic achievements at the student and school levels, (2) the mediation of students' perceived autonomy and interest in ICT use acting between students' ICT use and their academic achievements, and (3) the role of school-level variables such as, school leadership and school's collaborative climate in shaping the impact of ICT use on academic achievements.

2.1. ICT use and academic achievements

There has been a long debate on the relationship between students' ICT use and their academic achievements. From the constructivist perspectives, students' ICT use facilitates the development of learner autonomy, expression of thoughts and negotiation of meaning among learners, which eventually lead to enhancement in student learning outcomes (Chiao & Chiu, 2018). Nevertheless, results from large-scale international assessment on ICT use and academic achievements are inconclusive. Zhang and Liu (2016) examined the trends of relationships between ICT use and students' academic achievements across the five waves of PISA studies from 2000 to 2012, and identified that students' ICT use was negatively correlated with their science and mathematics achievements.

In PISA studies, students' ICT use can be categorized into ICT use at school, ICT use outside school for schoolwork, ICT use for entertainment and ICT use for social interaction (OECD, 2016b). Different types of students' ICT use manifested different relationships with students' academic achievements across the academic subjects being examined (Odell et al., 2020). Based on PISA 2015, Hu et al. (2018) and Gómez-Fernández and Mediavilla (2021) revealed that students' ICT use for entertainment correlated positively with their academic achievements while negative correlations were found between students' ICT use outside school for schoolwork and achievements. On the other hand, by analyzing the Dutch PISA 2015 sample, Gubbels et al. (2020) found that students with moderate ICT use outside school for schoolwork had the highest performance in reading, whereas frequent use of ICT outside school for leisure correlated negatively with reading scores. Students' ICT use for social interaction and ICT use for entertainment were found to correlate negatively with students' academic achievements (Gómez-Fernández & Mediavilla, 2021; Hu et al., 2018; Odell et al., 2020; Park & Weng, 2020). Likewise, negative correlation between ICT use at school and academic achievements was also identified (Hu et al., 2018).

While the relationships between students' ICT use and their academic achievements were inconclusive, findings from some studies indicating that students' ICT use for learning, social interaction or leisure helped promote students' autonomy and interest in harnessing technology (Burbat, 2016; Honarzad & Rassaei, 2019; Liu et al., 2018). In short, if students are given ample opportunities to harness technology through school work and daily activities, they may develop the ability to use technology to support their own learning during private time. Thus, students' ICT use may exert an indirect effect on academic achievements via students' autonomy and interest in ICT use. However, little is known about these mediation effects in large-scale assessments such as PISA. Thus, the purpose of the present study was to unfold how the interplay of these variables affected academic achievements.

2.2. Autonomy in ICT use, interest in ICT use, competency in ICT use and academic achievements

In the context of PISA studies, students' autonomy in ICT use, interest in ICT use and competency in ICT use refer respectively to students taking control of their learning through ICT use, students' intrinsic motivation to use ICT, and students' ICT-related skills and knowledge (Park & Weng, 2020).

In the trend analysis of five waves of PISA studies from 2000 to 2012 conducted by Zhang and Liu (2016), students' competency in ICT use was found to correlate positively with science and mathematics and reading achievements. Positive associations between students' autonomy in ICT use and academic achievements were identified in PISA 2015 (Gómez-Fernández & Mediavilla, 2021; Hu et al., 2018; Park & Weng, 2020; Petko et al., 2017). Similar relationships between students' interest in ICT use and academic achievements were also identified in the above studies. A non-linear relationship was found between students' interest in ICT use and reading achievements in the Dutch PISA 2015 sample (Gubbels et al., 2020). It was found that students with moderate interest in ICT use had the highest scores in reading. Inconsistent results of the relationship between students' ICT interest and academic achievements were also found across countries. In the regression analysis of PISA 2015 data conducted by Meng et al. (2019), students' interest in ICT use was found to correlate positively with students' academic achievements in China, in contrast to the negative correlation in Germany.

As illustrated above, these ICT traits exert significant impacts on students' academic achievements and can play a pivotal role in mediating the influence of other ICT-related variables, such as ICT use and ICT availability on academic achievements.

2.3. ICT availability at school, ICT availability at home and academic achievements

In PISA studies, ICT availability can be categorized into ICT availability at school and at home. Building the ICT infrastructure and providing students the access to ICT resources is often seen as instrumental to ICT implementation in school (Hu et al., 2018). Zhang and Liu (2016), after controlling for demographic variables at the school level, found that the number of Internet-connected computers available to students exert positive influence on academic achievements across the five waves of PISA studies. Results also show that higher availability of computers per student in the schools correlated positively with students' academic achievements (Gómez-Fernández & Mediavilla, 2021). Similarly, ICT availability at home was found to correlate positively with students' reading scores in PISA 2015 by the analysis conducted by Yalcin (2018), in contrast to the negative correlation identified by Hu et al. (2018). Non-linear relationship was also revealed in the relationship between ICT availability at school and at home, and students' reading scores (Gubbels et al., 2020).

Similar to students' ICT use, ICT availability at school and at home may exert an indirect effect on students' academic achievements via students' autonomy in ICT use and students' interest in ICT use. These mediation or indirect effects remain underexplored in PISA studies.

2.4. School's transformational leadership, teachers' collaborative climate and academic achievements

In comparison to other system-wide education reform initiatives, infusing ICT in schools is often seen as more intricate and challenging. Effective implementation hinges not only on the provision of physical resources, it also depends on an array of organizational factors such as school leadership, the collaborative climate within a school (Amghar, 2019; Szeto, 2020). Among various school-level factors, fostering communities of practice for teachers, provision of a participative governance structure that empower teachers to make autonomous decisions (Avidov-Ungar & Hanin-Itzak, 2019), and principals' leadership, particularly, transformational leadership was found to be pivotal to sustaining change in school (Wu et al., 2020). Transformational leadership is often

conceptualized as a leadership trait in which school leaders possess the capacity to (1) establish common goals and shared visions, (2) cultivate mutual trust and support among staff, (3) empower teachers to take risk and experiment with new practices, and (4) support professional development (Bush, 2018;). Demir (2021) argued that factors affecting teachers' adoption of new practices can be irrational or sociocultural, and that trust, collegiality, social support and professional exchange are instrumental social forces that help sustain change and innovations in school. Tam et al. (2018) identified these social forces as the essential social fabrics of a school which enable teachers to have access to expertise and collegial support, and make them feel safe in risk-taking. Transformational leadership played a critical role in shaping teachers' collaborative climate for change and exerted an indirect effect on fostering innovative practices and students' academic achievements (Li & Choi, 2014). Small positive associations between teachers' collaborative climate and students' academic achievements were identified in the German PISA 2012 sample (Mora-Ruano et al., 2019). On the other hand, working on the PISA 2015 data, Wu et al. (2020) unveiled that school leadership had a direct positive relationship with teachers' collaborative climate and students' science achievements. In our present study, we attempted to examine how the interplay of school leadership, teachers' collaborative climate and ICT-related variables such students' autonomy in ICT use and students' interest in ICT use impacted on students' academic achievements at the school level.

2.5. Socioeconomic status and academic achievements

Socioeconomic status (ESCS) in PISA studies is operationally defined as a measure of students' access to family resources including human social, cultural, and financial capitals, which identify the social position of the student's family (Avvisati, 2020). ESCS was found to have a strong correlation with students' academic achievements (Chiao & Chiu, 2018). In the present study, in order to control for the influence of student's socioeconomic status on academic achievements, ESCS was used as a control variable for the analysis at the student-level and school-level.

2.6. The present study

Apparently, the analytical methods employed in most of studies on large-scale international assessments are mainly regression analysis or hierarchical linear modelling (HLM) which is inadequate to unfold the complex relationships between ICT-related variables and students' academic achievements, particularly, the subtle indirect effects exerted among variables. To circumvent these limitations, we employed multi-level structural equation modelling (MSEM) techniques to examine how ICT-related variables compete with one another and how they mediate the impact of ICT on students' academic achievements. MSEM enables variables at different levels to interact with one another along multiple paths.

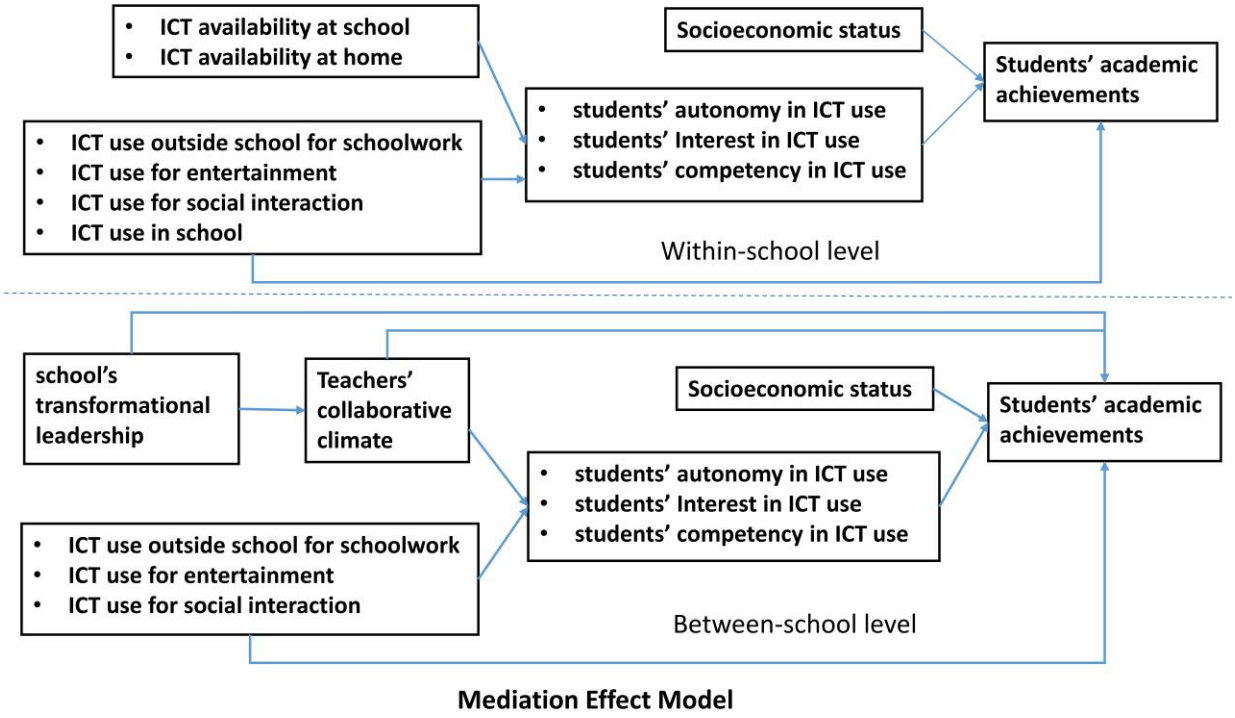
We hypothesized that students' autonomy and interest in ICT use played a mediating role in the relationship between students' ICT use and students' academic achievements. In short, students' ICT use could help develop their autonomy and interest in ICT use which subsequently influenced on students' academic achievements. At the school level, as discussed in previous section, school's transformational leadership had a positive impact on teachers' collaborative climate while school's collaborative climate was found to be conducive to effective ICT implementation. Thus, we anticipated that teachers' collaborative climate would have a positive impact on students' ICT-related latent traits, such as students' autonomy, interest and competence in ICT use. As such, we would like to examine how teachers' collaborative climate mediated the relationship between school's transformational leadership and students' ICT-related traits. The conceptual framework depicted in Figure 1 highlights the complex structural relationship among students' academic achievements, ICT use, ICT related traits and various contextual variables at both the within-school and the between-school levels.

Specifically, two-level random intercept structural equation models were constructed based on the PISA 2015 dataset. Student-level variables included students' academic achievements, students' autonomy in ICT use, students' interest in ICT use, and students' competence in ICT use, while school-level variables encompassed school's transformational leadership, teachers' collaborative climate and school-level ICT resources. Based on this framework, we examined if the multi-level contextual variables had any direct and/or indirect effects in mediating the impact of ICT use on student achievements. The research questions are threefold:

- RQ1. Based on the PISA 2015 dataset, to what extent did students' autonomy in ICT use, students' interest in ICT use, students' competence in ICT use, and their ICT use in various contexts impact on students' academic achievements?
- RQ2. To what extent did students' autonomy in ICT use and students' interest in ICT use mediate the impact of students' ICT use and ICT availability on students' academic achievements?

- RQ3. Did school's transformational leadership and teachers' collaborative climate have a role to play in shaping the impact of ICT use on students' academic achievements?

Figure 1. A conceptual framework depicting a multilevel structural relationships among students' academic achievements, ICT use and various ICT-related variables



3. Method

3.1. Data source and sample

The presented study was grounded on the data derived from the large-scale comparative study: Programme for International Student Assessment (PISA) conducted in 2015, under the auspices of Organization for Economic Co-operation and Development (OECD). Administered in every three years, PISA assesses how well 15-year-old students apply their knowledge and skills in three key domains: reading, mathematics and science (with a stronger focus on a selected domain in each three-year cycle) to address challenges that emerge from their everyday-life experiences. In PISA 2015, a stronger focus was centered on science (OECD, 2016b).

The main reason for choosing PISA 2015 dataset is that it contains variables such as ICT use outside school for schoolwork and teachers' perceived transformational leadership which were not included in the previous cycles of PISA and PISA 2018 studies.

We utilized the school, teacher and student questionnaire of PISA 2015 dataset to examine if students' ICT use in various contexts had any impact on their academic achievements among those high-achieving countries and economies participated in PISA 2015, and how this impact was mediated by students' autonomy in ICT use and students' interest in ICT use.

We initially selected those participating countries or economies whose national mean science literacy scores were ranked top 20 in PISA 2015. Among these 20 countries or economies, only 7 of them participated in all the four questionnaire surveys relevant to the present study: Cognitive test scores, Student Questionnaire, ICT familiarity Questionnaire, and Teacher Questionnaire. These 7 countries or economies, which include Chinese Taipei, Macau, Hong Kong, Beijing-Shanghai-Jiangsu-Guangdong (BSJG China), Korea, Australia and Germany, were finally selected for our study. This selected sample comprised altogether 1,847 schools, 9024 teachers and 53,999 students.

3.2. Data analysis

3.2.1. Variables

Variables for the present study were selected from the Cognitive tests, ICT Familiarity Questionnaire, Teacher Questionnaire and Student Questionnaire of PISA 2015. As listed in Table 1, some variables were composite variables created by the PISA research team, while others were latent variables and their associated indicators.

Table 1. List of within-school level and between-school level variables

Student-level (Within-school level)	School-level (Between-school level)	Variable label/ question items in PISA 2015 Dataset
Variables from Cognitive Tests		
ACW	ACB	Students' academic achievements
SCIE	random intercept	Plausible values 1-10 in Science
MATH	random intercept	Plausible values 1-10 in Mathematics
READ	random intercept	Plausible values 1-10 in Reading
Variables from ICT Familiarity Questionnaire		
SOIAICT		Students' ICT use for social interaction
COMPICT		Students' competence in ICT use
USESCH		Use of ICT at school in general
HOMESCH		ICT use outside of school for schoolwork
ENTUSE		ICT use outside of school leisure
ICTSCH		ICT available at School Index
ICTRES		ICT resources at home
ATW	ATB	Students' autonomy in ICT use
IC015Q02NA	random intercept	If I need new software, I install it by myself.
IC015Q03NA	random intercept	I read information about digital devices independently.
IC015Q05NA	random intercept	I use digital devices as I want to use them.
IC015Q07NA	random intercept	If I have a problem with digital devices I start to solve it on my own.
IC015Q09NA	random intercept	If I need a new application, I choose it by myself.
ITW	ITB	Students' interest in ICT use
IC013Q04NA	random intercept	The Internet is a great resource for obtaining information I am interested in (e.g., news, sports).
IC013Q05NA	random intercept	It is very useful to have social networks on the Internet.
IC013Q11NA	random intercept	I am really excited discovering new digital devices or applications.
IC013Q13NA	random intercept	I like using digital devices.
Variables from Teacher Questionnaire		
-	TCLEAD	Teachers view on school's transformational leadership
-	EXCHT	Teachers' collaborative climate for exchange and co-ordination for teaching
Variables from Student Questionnaire		
ESCS		Index of economic, social and cultural status
W_FSTUWT	-	Final adjusted student weight
-	W_SCHGRNRABWT	Final adjusted school weight

3.2.2. Students' academic achievements

In PISA 2015, science literacy was measured by students' procedural and epistemic knowledge about science. For mathematics, PISA assessed the extent to which students were able to apply mathematics to solve real-world problems. Students' reading literacy was assessed based on how well they comprehended, used and reflected on written texts. As students were assessed with only a small subset of the total item pool, PISA employed imputation methods to report students' academic achievements in order to reduce measurement error. For each literacy domain, PISA used 10 plausible values to represent students' performance, e.g., PV1SCIE – PV10SCIE for science, PV1MATH – PV10MATH for mathematics, and PV1READ - PV10READ for reading. For any analysis involving estimates of students' academic achievements, it should be conducted 10 times (each with one selected plausible value), and the final estimate is obtained by pooling results of the 10 individual analyses. In the present study, we defined students' academic achievements as a latent variable which comprising the math

score, science score and reading score as indictors. The within-school level and between-school level components of students' academic achievements were denoted as ACW and ACB respectively (see Table 1).

3.2.3. Student's socioeconomic status

In Student Questionnaire, PISA created an index, ESCS for gauging student's economic, social and cultural status. In the present study, ESCS served as controlled variables. We would like to see how students' ICT use in various contexts, students' autonomy in ICT use and students' interest in ICT use impacted on their academic achievements after controlling the effects due to ESCS.

3.2.4. ICT availability, students' ICT use in various contexts, students' autonomy and interest in ICT use

Based on the ICT Familiarity Questionnaire, PISA created a number of composite variables to measure students' ICT use, for instance, ICT availability at school and at home indices, and ICT resources in general were measured with the composite variables ICTSCH, and ICTRES respectively. According to the PISA 2015 technical report, the composite variable ICTRES comprises six items, asking students about the ICT availability at home including educational software, a link to the Internet, the number of cell phones with Internet access, computers, tablets and e-book readers.

Students' ICT use was differentiated by the location and purpose of technology use, e.g., use of ICT at school in general (USESCH), ICT use outside school for schoolwork (HOMESCH) and ICT use for leisure (ENTUSE). In addition, students' traits related to ICT use included students' competence in ICT use (COMPICT) and social use of ICT (SOIAICT). In addition, students' ICT related traits also included students' interest in ICT use and students' autonomy in ICT use. For multilevel structural equation modelling, the variation of each of these variables were partitioned into a within-school level and a between-school level components for analysis. Taking HOMESCH as an example, the within-school level component of HOMESCH is the variance of individual students' scores about their school mean scores, whereas, the between-school level component of HOMESCH represents the variance of individual school mean scores about the entire sample mean. Thus, the greater the between-school level variance, the greater the diversity is found among schools in terms of their mean scores of HOMESCH.

As illustrated in their technical report, PISA used 5 items: IC015Q02NA, IC015Q03NA, IC015Q05NA, IC015Q07NA and IC015Q09NA to measure students' autonomy in ICT Use. In the present study, the within-school level and between-school level components of students' autonomy in ICT use were denoted as ATW and ATB respectively. To improve model fitting in two-level CFA, IC015Q05NA was deleted from ATB. For students' interest in ICT use, PISA used 6 items to measure students' ICT interest. In the present study, the number of items were reduced to 4 to enhance model-fitting after confirmation factor analysis. The 4 items were: C013Q04NA, IC013Q05NA, IC013Q11NA, and IC013Q13NA as shown in Table 1. Similarly, for the purpose of multilevel structural equation modelling, the variation of students' interest in ICT use was partitioned into within-school level and between-school level components denoted as ITW and ITB respectively.

3.2.5. School's transformational leadership and teachers' collaborative climate

In Teacher Questionnaire, PISA created a composite variable, TCLEAD to gauge teachers' views on school's transformational leadership which include teachers' involvement in decision-making, principal's awareness of teachers' needs and respect for teachers as professionals, principal's capacity to inspire innovative ideas and build consensus with teachers in priority- and goal-setting. Teachers' collaborative climate was measured by teacher's exchange and coordination for teaching via EXCHT.

3.2.6. Multilevel structural equation modelling (MSEM)

As the structure of PISA data was intrinsically hierarchical, in which students and teachers data were nested in schools. Treating the single level data as independent observations may result in underestimating standard errors of regression coefficients and overstating statistical significance. In the present study, two-level random intercept structural equation models were constructed in which the variations in the variables selected from the student questionnaires, such as, HOMESCH, ENTUSE, SOIAICT, INTICT, COMPICT and ESCS, were partitioned into a within-school level and a between-school level components. While ACW, ATW and ITW were modeled as the

within-school level components of students' academic achievements, students' autonomy in ICT use, and students' interest in ICT use respectively, ACB, ATB and ITB are the between-school components representing random intercepts of the models. The between-school level variables, TCLEAD and EXCHT were derived by averaging the aggregated scores of teachers' responses collected from each school. Based on the conceptual framework, a two-level random-intercept structural equation model: Mediation Effect Model was constructed to examine the complex structural relationships among students' academic achievements, students' ICT use in various contexts, students' competency in ICT use, students' autonomy in ICT use and students' interest in ICT use.

4. Results

4.1. Mediation effect model

Based on the conceptual framework, a two-level mediation effect model was constructed (see Figure 2). The fitting indices given in Table 2 indicate that the RMSEA indices of the three models are all smaller than 0.05 and all CFI and TLI are greater than or close to 0.9, showing that the three models are of good fit.

Table 2. Fitting indices of two-level structural equation models

	df	χ^2	RMSEA	CFI	TLI
Mediation effect model	245	5306.467	0.023	0.90	0.89

At the within-school level, as shown in Figure 2, ATW, ITW, and HOMESCH exerted a positive direct effect on students' academic achievements with a loading of 0.309, 0.263 and 0.046 respectively, in contrast to the negative effects exerted by ENTUSE, SOIAICT, COMPICT and USESCH which ranged from -0.147 to -0.163. However, as ENTUSE, SOIAICT, COMPICT exerted a moderate to large positive direct effect on ATW and ITW, ranging from 0.109 to 0.452, they had a positive indirect effect on students' academic achievements mediated by ATW and ITW.

ICTRES exerted a large direct effect on ITW and COMPICT, and a small effect on ATW.

Summing over the direct and indirect effects, HOMESCH, ICTRES and COMPICT had a positive total effect on students' academic achievements (see Table 3). USESCH and ICTSCH were the two ICT-related variables showing no effect or a negative effect on ATW, ITW and students' academic achievements.

Table 3. Total effects and indirect effects exerted by ICT-related variables and school-level variables on students' academic achievements

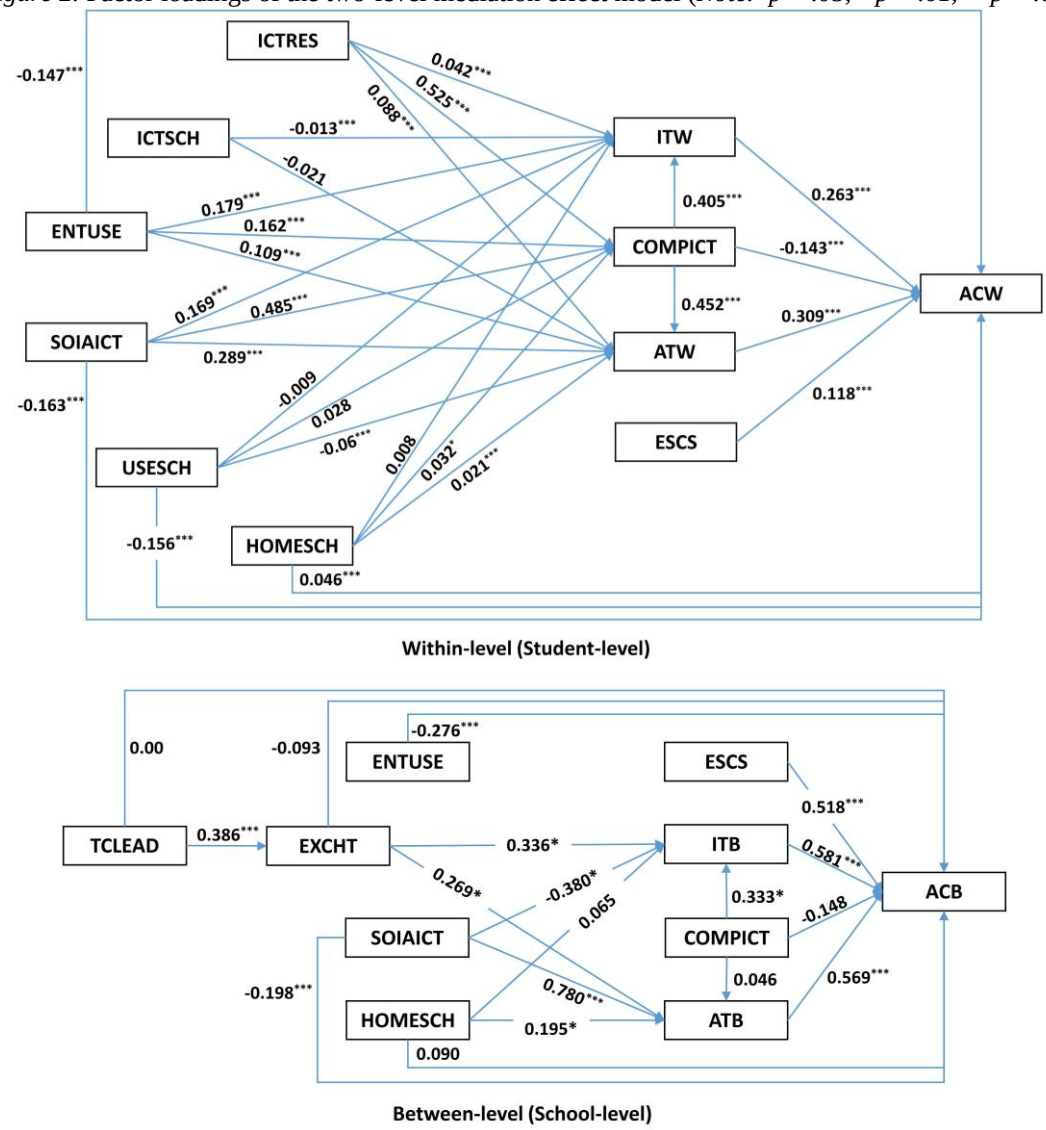
	ACW		ACB	
	Total effect	Total indirect effect	Total effect	Total indirect effect
ATW	0.305^{***}	-		
ATB	-	-	0.529^{**}	-
ITW	0.260^{***}	-	-	-
ITB	-	-	0.584^{**}	-
COMPICT	0.102^{***}	0.244^{***}	0.073	0.225
SOIAICT	0.020	0.179^{***}	0.022	0.199
ENTUSE	-0.049^{***}	0.096^{***}	-0.272	-
HOMESCH	0.057^{**}	0.012^{*}	0.240^{**}	0.150^{*}
USESCH	-0.174^{***}	-0.018^{***}	-	-
ICTRES	0.038^{***}	0.038^{***}	-	-
ICTSCH	-0.010^{*}	-0.010^{*}	-	-
EXCHT	-	-	0.276^{**}	0.371^{***}
TCLEAD	-	-	0.107^{*}	0.107^{*}

Note. (W) Within-school level; (B): Between-school level; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

At the between-school level, ATB and ITB exerted a large direct effects on students' academic achievements with a loading of 0.569 and 0.518 respectively. HOMESCH exerted a moderate positive effect on ATW. As a result, HOMESCH had a positive indirect effect on students' academic achievements with a loading of 0.057 mediated by ATW (see Table 3). On the other hand, EXCHT exerted a strong positive direct effect on ATB and ITB with a loading of 0.269 and 0.336 respectively (see Figure 2). As a result, EXCHT manifested moderate positive total effects on students' academic achievements with the indirect effects mediated by ATB and ITB.

TCLEAD exerted a strong positive direct effect on EXCHT (0.393), resulting in a small positive total effect (0.107) on students' academic achievements.

Figure 2. Factor loadings of the two-level mediation effect model (*Note.* $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$)



5. Discussion and conclusion

The results of the present study reveal that students' autonomy in ICT use and students' interest in ICT use at both the within-school and between-school levels, exerted a significantly large positive direct effect on students' academic achievements across students' academic achievements comprising science, mathematics and reading after controlling for the effects of ESCS. In addition, these latent traits also played a significant role in mediating the impact of ICT related variables on students' academic achievements. These ICT related variables include students' ICT use outside school for schoolwork, students' ICT use for leisure (ENTUSE) and students' competence in ICT use (COMPICT) and students' ICT use for social interaction (SOIAICT).

The results of the present study corroborate with findings from studies on student autonomy, indicating that students' perceptions of autonomy and academic competence predict students' learning engagement (Hafen et al., 2012). As explicated by Skinner et al. (2008), students tend to look for and flourish in environments where they are empowered to exercise their autonomy and apply their knowledge. In short, enhancing students' autonomy may lead to an increase in their engagement in learning. González and Paoloni (2015) echoed that students' autonomy in ICT use positively predicted their motivation, metacognitive strategies and learning performance. By taking a close look at students' autonomy in ICT use as defined in PISA 2015, it is not difficult to see that the items were devised for assessing students' metacognitive abilities related to ICT use, e.g., "If I

have a problem with digital devices I start to solve it on my own," "I read information about digital devices independently," etc. So, this latent trait is not about the freedom students enjoyed in using ICT, but their abilities to harness and use technology for learning. Similarly, students' ICT interest in PISA 2015 is more than their liking for ICT. It probes into students' epistemological beliefs about ICT use and motivation to advance their knowledge related to ICT use, e.g., "The Internet is a great resource for obtaining information I am interested in (e.g., news, sports, dictionary)," "I am really excited discovering new digital devices or applications," etc. In short, the two latent traits seemingly encompass the necessary attributes or competence that enable students to move away from surface learning. Thus, these latent traits related to ICT use apparently played a pivotal role in enhancing students' engagement in learning and academic achievements.

Regarding students' competence in ICT use (COMPICT), while at the within-school level, its direct effect on students' academic achievements were all negative, its indirect effect as mediated by students' autonomy in ICT use was positive and significant, resulting in a positive and significant total effect exerting on students' academic achievements (see Table 2). In a similar fashion, students' ICT use for social interaction (SOIAICT) and for leisure (ENTUSE) exerted a negative effect on students' academic achievements. There were a lot of negative connotations about the impact of students' social use of ICT on their academic achievements. As such, SOIAICT and ENTUSE has been regarded as a negative determinant of academic success and considered a nuisance to student learning (Hu et al., 2018; OECD, 2016a). Yet, taking a closer look at the MSEM results, both SOIAICT and ENTUSE exert a significant positive indirect effect on students' academic achievements as mediated by ATW and ITW at the within-school level and as mediated by ATB and ITB at the between-school level, though their resulting total effects remain negative or insignificant. The effects of students' social use of ICT should deserve more attention in future studies. In particular, it is worthy of examining whether a nonlinear relationship exists between students' academic achievements and their ICT use for leisure and social interaction as this kind of nonlinear relationship was revealed in some PISA studies discussed above (Odell et al., 2020), indicating that moderate or regulated social use of ICT may have a positive impact on students' performance.

It is also noteworthy that, while students' ICT use outside school for schoolwork were found to have either no effects or negative effects on students' academic achievements in a number of studies on PISA data (Hu et al., 2018; Zhang & Liu, 2016), the results of the present study indicate that students' ICT use outside school for schoolwork (HOMESCH) exerts a significant positive direct effect on students' academic achievements at the student level. It is noteworthy that the indirect effects of HOMESCH acting on students' academic achievements are mediated by students' autonomy in ICT use and students' interest in ICT use. This indicates that students' use of ICT outside school for schoolwork possesses the necessary affordance for nurturing students' autonomy and interest in ICT use which leads to their success in academic performance. We argue that informal contexts such as the home environments offer students a more relaxed, secured and autonomous learning space where they can explore, select and orchestrate different technologies for problem-solving, and that this kind of latent ability can be transferred and applied across disciplines. Thus, in future PISA studies, it is worth probing deeper into the connection between the types of schoolwork assigned to students, students' autonomy in ICT use and their generic cognitive and metacognitive skills.

Likewise, ICT availability at home (ICTRES) exerted a positive indirect effect on students' academic achievements mediated by students' autonomy in ICT use and students' interest in ICT use. Obviously, the availability of ICT resources at home would amplify students' capacity in accomplishing their schoolwork and offer more opportunities for students to develop their autonomy in ICT use. Nonetheless, ICT availability at school (ICTSCH) and the general use of ICT at school (USESCH) did not manifest the same effects on students' academic achievements as compared to ICTRES and HOMESCH. Interestingly, USESCH and ICTSCH exerted either no effect or a negative effect on students' autonomy in ICT use and their academic achievements. This suggests that mere provision and use of ICT resources at school did not necessarily guarantee success in student performance. It depends on how technology is being used pedagogically and whether students are able to develop their autonomy in learning with technology in and beyond the classroom processes.

Looking from a broader perspective, teachers' professional exchange and coordination for teaching (EXCHT) exerted significant positive indirect and total effects on Science, Mathematics and Reading which were mediated by students' perceived autonomy related to ICT use (ATB). While EXCHT exerted a significant positive direct effect on ATB, teachers' perceived transformational leadership impacted positively on EXCHT. As mentioned in previous sections, there have been ample studies suggesting that principal's transformational leadership is conducive to cultivating a collaborative climate in which teachers are empowered to experiment with new practices related to pedagogical use of emerging technologies. So, it would be interesting to examine if teachers' pedagogical use of technology mediates the impact of school leadership and school collaborative climate on students' perceived autonomy related to ICT use in future PISA studies. From a methodological point of view, multilevel structural equation modelling helps unravel the complex structural interplay between variables. By

teasing out the direct effects as well as indirect effects between variables, one can gain a more complete picture for discerning the impact of ICT use on students' academic achievements.

In sum, the findings of the present study can be summarized as follows:

RQ1. Based on the PISA 2015 dataset, to what extent did students' autonomy in ICT use, students' interest in ICT use and students' competence in ICT use, ICT availability at home and ICT availability at school impact on students' academic achievements?

Based on the results derived from the multilevel structural equation model, students' autonomy in ICT use and students' interest in ICT use were found to the determining variables which exert a large positive effect on students' academic achievements at both the student and school levels. Among students' ICT use in various contexts, students' ICT use outside school for schoolwork was found to exert a positive direct on students' academic achievements. Students' ICT use at school, students' ICT use for social interactions and students' ICT use for leisure were found to exert a negative direct effect on students' academic achievements.

RQ2. To what extent did students' autonomy ICT use and students' interest in ICT use mediate the impact of students' ICT use and ICT availability on students' academic achievements?

Students' autonomy in ICT use and students' interest in ICT use played a pivotal role in mediating the positive effects of ICT-related variables on students' academic achievements. These ICT-related variables include students' ICT use outside school for schoolwork, students' ICT use for social interaction, students' ICT use for entertainment, students' competency in ICT use and ICT availability at home. As a results, students' ICT use outside school for schoolwork, students' competency in ICT and use ICT availability at home manifested a positive total effect on students' academic achievements.

RQ3. Did school's transformational leadership and teachers' collaborative climate have a role to play in shaping the impact of ICT use on students' academic achievements?

At the school level, teachers' collaborative climate exerted a strong direct effect on students' autonomy in ICT use and students' interest in ICT use. As a result, it had a positive total effect on students' academic achievements, with a positive indirect effect mediated by students' autonomy in ICT use and students' interest in ICT use. Likewise, school's transformational leadership exerted a positive direct effect on teachers' collaborative climate, resulting in a positive total effect on students' academic achievements, with an indirect effect mediated by teachers' collaborative climate, students' autonomy in ICT use and students' interest in ICT use.

6. Limitations, implications and future directions

One of the limitations of this study is that among the top 20 high-achieving countries or economies, only 7 of them participated in all the four questionnaire surveys relevant to the present study. As such, 7 countries or economies were involved in the present study. Nonetheless, this selected sample comprised altogether 1,847 schools, 9024 teachers and 53,999 students. To further deepen our understanding of the impacts of ICT use across different regions, selecting data from a larger sample of countries is necessary. Nonetheless, the purpose of this study is not to make any over-generalized claims, but to gain more insights into what and how ICT related factors impinged on students' success in high-achieving countries and economies. Thus, we hope the findings of this study could shed lights on discerning the impact of ICT use on students' academic achievements and pave the way for further studies.

The pedagogical implication of this study is that empowering students to learn with technology is seemingly the key for leveraging the potential of ICT in education. Students need to develop their affection and sense of autonomy or ownership in using ICT to support their daily work. The mere provision of technology at school is not adequate to promote deep learning. In and out of the classroom, it is thus necessary to provide students more opportunities to engage in meaningful learning with the support of technology.

Nonetheless, further research is needed to explore (1) how students' autonomy in ICT use is associated with students' cognitive and metacognitive abilities; (2) the nonlinear effect of students' social use of ICT on students' academic achievements; (3) how pedagogical factors come into play in students' academic achievements; and (4) how teachers' pedagogical use of technology engenders students' autonomy in ICT use

and mediates the relationship between school collaborative climate and students' autonomy in ICT use. These are a few possible future research directions which should deserve more attention.

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