Routledge
Taylor & Francis Group

Research in Science & Technological Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/crst20

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To cite this article: Siqi Li , Xiufeng Liu , Jennifer Tripp & Yang Yang (2020): From ICT availability to student science achievement: mediation effects of ICT psychological need satisfactions and interest across genders, Research in Science & Technological Education, DOI: 10.1080/02635143.2020.1830269

To link to this article: https://doi.org/10.1080/02635143.2020.1830269

Published online: 06 Oct 2020.

RESEARCH IN SCIENCE & TECHNOLOGICAL EDUCATION
https://doi.org/10.1080/02635143.2020.1830269

From ICT availability to student science achievement: mediation effects of ICT psychological need satisfactions and interest across genders

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ABSTRACT

Background: Researchers have acknowledged that examining ICT in relation to disciplinary learning outcomes could offer a promising, synergistic research path forward. A number of empirical studies have been done to determine the relationship between ICT-related variables and students' science achievement. However, the mechanism of the relationships remains unclear. Thus, in-depth investigations of the above relationships are needed.
Purpose: This study examined the mechanism of how students' ICT availability, psychological need, satisfactions, and interest are associated with science achievement based on gender.
Sample: This study used data of Program for International Student Assessment (PISA) 2015 B-J-S-G student questionnaire. B-S-J-G refers to the four PISA-participating China mainland provinces: Beijing, Shanghai, Jiangsu, and Guangdong, which includes 9841 students.
Design and Methods: Underpinning by Self-Determination Theory (STD), a hypothesized model from ICT availability at home to science achievement that mediated by ICT psychological need, satisfactions, and interest were built. The model was tested by Structural Equation Modelling (SEM) along with the investigation of interrelationships among the factors in the model.
Results: Findings from the path analysis indicated that (i) ICT availability at home has positive indirect relationships with science achievement and positive direct relationships with other ICT variables; (ii) ICT autonomy and interest have positive relationships with science achievement; (iii) ICT social-relatedness and competence have negative and no relationships with science achievement, respectively; and (iv) the relationships between ICT availability at home and science achievement varied across genders.
Conclusion: A valid model of relationships from ICT availability to students' science achievement that mediated by ICT psychological needs and interest was established. Based on the model, recommendations of developing students' ICT interest and autonomy, especially for female students, were provided. Further research could offer keen insights into the areas of ICT investment and practice.

KEYWORDS
Secondary education; ICT in education; science performance; gender studies

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Introduction

In the information age, educational reforms across the globe have emphasized technological literacy, and many countries have invested considerable resources towards information and communication technologies, or ICT (Bybee 2013; Luu and Freeman 2010; De Witte and Rogge 2014). Over the years, ICT has broadened in scope to include a range of technological tools and resources that can be used to create, share, store, and manage information. Given the rapid development of ICT and its increased presence in everyday life, the importance of effectively using ICT to process, evaluate, create, and share knowledge with others has become evident. Researchers have acknowledged that examining ICT in relation to disciplinary learning outcomes could offer a promising, synergistic research path forward (Ladbrook and Parr 2015; Pérez-Sanagustín et al. 2017).

The relationship between ICT use and student achievement has been studied extensively. Students' ICT use – specifically for science education – has been widely perceived by researchers as an important factor for students' science learning (Skryabin et al. 2015; Zhang and Liu 2016). A number of studies have explored the impact of students' ICT availability on achievement. However, the above research has garnered mixed results; some findings indicate that ICT availability positively influences students' achievement (Erdogdu and Erdogdu 2015; Lee and Wu 2012), while others document negative or no impacts (Bulut and Cutumisu 2018; Luu and Freeman 2010). These inconsistent findings might be partly due to focusing only on the direct relationship between students' ICT availability and achievement, without considering indirect relationships through other ICT use factors. For example, ICT use quality (Hu et al. 2018) and frequency (Zhang and Liu 2016) might be helpful in explaining the relationship between ICT availability and science achievement, yet the mechanism, i.e., the pathways and interrelationships between those factors, remains unclear. Consequently, further research that considers both direct and indirect relationships is necessary.

In addition, with respect to the relationships between ICT use variables and science achievement, more attention has been directed at examining the purpose, time, and frequency of ICT use, while less attention has been given to the influence of student-related variables (Skryabin et al. 2015), including students' ICT psychological need satisfactions (competence, autonomy, social-relatedness) (Deci and Ryan 2000) and interest in ICT use. These variables address students' quality of ICT use, which might influence students' academic performance (Areepattamannil and Santos 2019). As such, additional research that explores the mechanism by which students' psychological need satisfactions and interest in ICT use might impact students' academic achievement is necessary (Hu et al. 2018).

Recently, several studies have indicated that ICT use results in a larger positive impact on academic performance among female students as compared with male students (Basri, Alandejani, and Almadani 2018; Chiao and Chiu 2018). For example, Chiao and Chiu (2018) found that female students who had higher ICT usage times had better academic achievement as compared with male students. This research suggests that the relationships between ICT variables and students' achievement might differ across genders. Accordingly, further investigation of possible gender differences is necessary in order to offer best practices for ICT use that supports science learning for all students, regardless of gender. Moreover, while previous research examines students' gender differences in ICT access, skills, and use frequency (Basri, Alandejani, and Almadani 2018; Chiao and Chiu 2018), few studies investigate gender differences in terms of students' ICT psychological need satisfactions and interest. Since psychological need satisfactions and interest might also be important for students' ICT use development and academic performance, it is meaningful to examine potential gender differences among these variables.

Research questions

To provide a more comprehensive and nuanced understanding of the relationships between ICT variables and academic achievement, this study aims to examine the mechanism by which students' ICT availability, psychological need satisfactions, and interest are associated with science achievement based on gender when controlling the influence of students' economic, social, and cultural status (ESCS) and science self-efficacy – two key factors affecting students' science performance (Kim 2018a; Jansen, Scherer, and Schroeders 2015). Specifically, this study answers the following research questions:

(1) What are the direct, indirect, and total effects of ICT availability, ICT psychological need satisfactions, and ICT interest on students' science achievement, controlling for ESCS and science self-efficacy?

(2) What are the gender differences in terms of ICT and science achievement?

2a. Do female students exhibit a different performance in ICT availability, ICT psychological need satisfactions, and ICT interest and science achievement compared with male students?

2b. Do any of the relationships between ICT availability, ICT psychological need satisfactions, and ICT interest and science achievement vary across genders?

Literature review

ICT availability at home

Numerous studies have shown that students' academic performance increases significantly when they have a computer at home and easy access to the Internet (Erdogdu and Erdogdu 2015; Lee and Wu 2012). For example, Erdogdu and Erdogdu (2015) indicated that the availability of an Internet connection at home had positive impacts. However, some studies revealed a more complex relationship between ICT availability and achievement. For instance, Bulut and Cutumisu (2018) observed that ICT availability at home was positively associated with science achievement in Turkey but not in Finland. Luu and Freeman (2010) found that ICT access at home was not significant in relation to scientific literacy for both Canada and Australia. In addition, other studies revealed that students' ICT availability at home had a negative association with science achievement (Hu et al. 2018; Lee and Wu 2012). Thus, the relationship between ICT availability at home and science achievement cannot be assumed.

ICT psychological need satisfactions

Existing research suggests that the three psychological need satisfactions – competence, autonomy, and relatedness – are associated with science achievement. For instance, Zhang and Liu (2016) found that students' ICT competence levels can predict students' academic achievement and that ICT competence is beneficial for science academic achievement, a result consistent with Luu and Freeman (2010). Moreover, Areepattamannil and Santos (2019) found that students' ICT competence and ICT autonomy were significantly positively related to students' science self-efficacy, which can influence students' science achievement. As compared with ICT competence, ICT autonomy was more strongly related to science dispositions, such as science self-efficacy and science enjoyment. Given these findings, there is some indication that ICT competence and autonomy might be positively associated with science achievement. In contrast, studies have shown that ICT social-relatedness is negatively associated with science achievement (Hu et al. 2018).

Despite these findings, the relationships among the ICT psychological need satisfaction variables remain unclear, and the ways in which these variables could influence other student ICT variables and relate to science achievement have not been studied. Previous studies have documented the psychological need satisfactions as ICT attitudinal constructs (Hu et al. 2018) or examined only one or two of the psychological need satisfactions in relation to achievement, without considering other variables (Luu and Freeman 2010; Zhang and Liu 2016). Further investigation is necessary to reveal the mechanism through which ICT need satisfactions may influence science achievement (Hu et al. 2018) and contribute to an in-depth discussion regarding the reasons behind the relationships.

ICT interest

Some studies have shown that students' ICT interest is related to students' learning. For example, Lee and Wu (2012) found a positive association between ICT interest and reading literacy. In addition, using PISA 2015 data, Hu et al. (2018) found that ICT interest had a significant relationship with students' science achievement. That is, students who had higher ICT interest also had higher science achievement and with a large magnitude, after controlling for other pronounced factors such as ESCS and gender. However, few studies have explored the relationship between ICT interest and science achievement. These findings warrant further exploration of the relationship between ICT interest and science achievement and map out possible relationships between ICT interest and other ICT factors.

Gender differences in ICT and science achievement

There are inconsistent results regarding gender differences related to ICT. Many studies have indicated that female students tend to have less positive attitudes towards ICT, have lower ICT competence, use ICT less frequently in their leisure time, and have fewer ICT skills as compared with their male peers (e.g., Drabowicz 2014; Vekiri and Chronaki 2008). For instance, Drabowicz (2014) revealed that males use computers and the Internet for educational purposes more frequently than females. In contrast, Aesaert and van Braak (2015) found that female participants had better technical ICT skills and higher-order ICT competencies than male participants. In addition, Chiao and Chiu (2018) study found that females in East Asia who spent more time on ICT for learning had better academic achievement outcomes and preferred online social interactions and online learning as compared with males. While many studies highlight gender differences related to ICT, some studies suggest a more gender-balanced picture, proposing that males and females no longer significantly differ in their attitudes toward computers and their computer usage time (Gumus and Atalmis 2011; Pamuk and Peker 2009). For instance, Tsai and Tsai

(2010) found that fourteen-year-old males and females in Taiwan had similar levels of computer and Internet self-efficacy, Internet use experience, and computer availability.

Previous research documents gender differences in science learning and shows that males outperform females in relevant achievement tests (Skryabin et al. 2015; Zhang and Liu 2016). On the other hand, some studies have indicated that the gender gap might already be closed in science achievement but that it still exists with respect to students' science attitudes and pursuit of science careers (Beekman and Ober 2015). Luu and Freeman (2010) studied both Canadian and Australian contexts and found that gender was not found to be a statistically significant predictor of science achievement. Other studies have suggested that a gender gap in science achievement still exists – that females tend to score lower on measures of science achievement (Miyake et al. 2010; Quinn and Cooc 2015). For example, Chi et al. (2018) found that male students had higher average science achievement, more positive science attitudes, interest, and enjoyment as compared with females of low social economic status backgrounds. Likewise, Lau and Lam (2017) found that females had lower overall science scores in all regions studied as compared with males. To date, no studies document the relationships among ICT psychological need satisfactions across gender and their relation to science achievement.

Conceptual framework

The conceptual framework underlying the research questions for this study is shown in Figure 1. Specifically, we hypothesized that ICT availability at home and students' ESCS impact students' ICT psychological needs, including ICT competence, ICT autonomy, and social-relatedness; the ICT psychological needs impact students' ICT interest through self-efficacy, which in turn, impact students' science achievement. This conceptual model was constructed by theories and previous literature described below.

Self-determination theory (SDT) is an empirically based theory, which represents a broad framework for human behavior, motivation, and personality development (Deci and Ryan 2000; Ryan and Deci 2017). SDT includes six interrelated mini-theories, one of which is the basic psychological needs theory. Psychological needs theory posits that an understanding of human behavior requires consideration of three innate psychological needs: competence, autonomy, and relatedness. In particular, competence refers to the belief that one has the ability to influence important outcomes in relation to one's own behavior (White 1959); autonomy refers to the desire to self-organize experience and behavior and to have activity

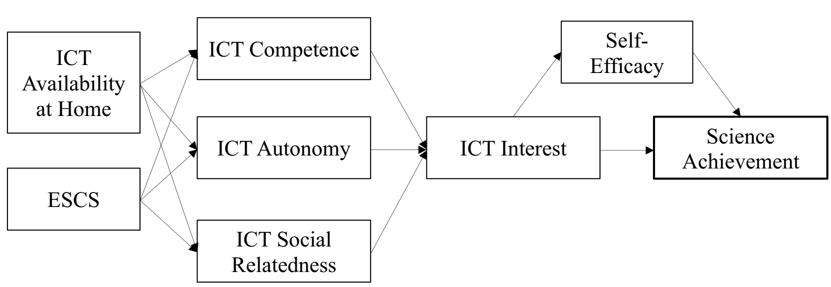

Figure 1. Conceptual framework.

be aligned with one's integrated sense of self (Deci and Ryan 2000); and relatedness refers to the desire to feel secure, connected to, or understood by others (Deci and Ryan 2000).

According to SDT, different degrees of the three psychological need satisfactions are associated with different qualities of behavior, including students' academic performance (Deci and Ryan 2000; Ryan and Deci 2017). As previous studies have demonstrated, when these needs are satisfied, they enable students to achieve optimal academic performance (Erturan-İlker et al. 2018; Black and Deci 2000). Thus, lower academic performance is typically associated with the psychological needs of competence, autonomy, or relatedness not being met (Deci and Ryan 2000).

With this theoretical foundation, this study considers ICT psychological need satisfactions, where ICT competence refers to students' beliefs in their ability to master the use of ICT; ICT autonomy refers to students' perceptions of personal independence in competently using ICT; and ICT social relatedness refers to students' feelings of connectedness to others when using ICT. Underpinned by this SDT perspective, the three ICT psychological need satisfactions may impact students' behavior in ICT use, which can, in turn, influence students' science learning performance when they engage in ICT tasks.

Interest is another key factor that is positively associated with students' academic performance (Krapp 2002). Based on an SDT perspective, Krapp (2002) discussed the associations between interest and psychological need satisfactions. A few studies have provided empirical evidence for this assumption, determining that psychological need satisfactions are necessary conditions for learners to develop interest, which, in turn, can influence their behavior (Lewalter and Krapp 2004; Minnaert 2007). Altogether, these studies suggest that, through the path of ICT interest, a possible association between ICT psychological need satisfactions and science achievement may exist.

For ESCS, researchers have reached an agreement that ESCS is a strong predictor of students' academic achievement, especially in science education (Ma and Wilkins 2002). With respect to ICT availability, studies have explored ICT availability in school and at home, and some studies have indicated that ICT availability at home – but not at school – was found to have a statistically significant relationship with academic achievement (Lee and Wu 2012). Thus, this study considers only ICT availability at home. In addition, ESCS and ICT availability are thought to be conditions that influence students' ICT performance, which has been examined in terms of frequency and interest in ICT use. When exploring the mechanism by which this occurs, previous studies typically consider resource factors before other variables (e.g., Kim 2018a, 2018b; Lee and Wu 2012). Therefore, this study's path considers ESCS and ICT availability at home as two factors that can predict other ICT variables, which, in turn, can predict science achievement.

Students' science self-efficacy is a final key factor that must be considered in the model, with previous studies indicating the important role of self-efficacy in predicting students' science achievement (Britner and Pajares 2006). Previous research also indicates that interest and self-efficacy are connected to each other and inform an individual's performance (Hidi, Berndorff, and Ainley 2002). With these theoretical and empirical underpinnings, we hypothesized that the impact of ICT interest on science achievement may be mediated by students' self-efficacy. We note that the above worldwide literature involving different countries should take into consideration of diverse social-cultural contexts of different education systems.

Method

Data and sample

The Programme for International Student Assessment (PISA) is a survey to test the skills and knowledge of 15-year-old students worldwide (OECD 2016a). In PISA 2015, approximately 540,000 students completed the assessment, representing about 29 million 15-year-olds in the schools of the 72 participating countries and economies. In addition to testing students' mathematics, science, and reading skills, and collecting background information about students and their family and school, PISA 2015 also offered optional questionnaire modules for students related to ICT.

This study applied B-S-J-G (China) data from PISA 2015 to test the hypothesized path model, the data were retrieved from the OECD website. B-S-J-G refers to the four PISA-participating China mainland provinces: Beijing, Shanghai, Jiangsu, and Guangdong. With extensive investment in education and ICT support over the past decades, Chinese schools gradually become one of the largest consumers of fast updated ICT and a large number of schools are well equipped in terms of hardware (Ministry of Education 2018). While ICT has been available to schools in developed countries for decades, it has been only recently that developing countries such as China are trying to catch up (Kozma and Vota 2014; Ministry of Education 2018). Therefore, research and practice of ICT implementation in China could provide insights on using ICT in education globally, especially for developing countries.

Specifically, Table 1 shows the demographic information for the B-S-J-G data. There were 9,841 student participants, which included 4,682 females and 5,159 males, accounting for 47.6% and 52.4% of the sample, respectively. Most of the participants were ninth and tenth graders, accounting for 90.3% of the student participants. To access students' demographic and ICT information, data from the student questionnaire and ICT familiarity questionnaire was utilized in this study.

Variables

Dependent variables

The major dependent (endogenous) variable of this study is students' science achievement, which was measured by 10 plausible values (PVs): PV1SCIE to PV10SCIE. In PISA 2015, students' science achievement was measured through different subsets of the test, and the scores were imputed based on the Item Response Theory (IRT) model, which generated 10 PVs for each knowledge domain to report students' underlying abilities. To provide a more

Table 1. Demographic information for the B-S-J-G data (N = 9841).

Demographic		Frequency	%
Gender	Male	5159	52.4
	Female	4682	47.6
Grade	7	94	1.0
	8	667	6.8
	9	4813	48.9
	10	4072	41.4
	11	189	1.9
	12	6	0.1

precise estimation, the PV method was applied using all 10 of the science PVs to represent students' overall science performance. The composite measure of science achievement was computed using the IEA International Database Analyzer (IDB Analyzer).

Focus independent variables

This study included five ICT variables as independent (exogenous) variables: (1) ICT availability at home (ICTHOME), which is an index based on the sum of students' availability of 11 ICT items such as a computer, tablet, and Internet at home; (2) ICT perceived competence (COMPICT, α = 0.80), which refers to the index of five items, such as 'I feel comfortable using digital devices that I am less familiar with'; (3) ICT perceived autonomy (AUTICT, α = 0.89), which refers to the index of five items, such as 'If I have a problem with digital devices I start to solve it on my own'; (4) ICT perceived social-relatedness (SOIAICT = 0.84), which refers to the index of four items, such as 'I like to share information about digital devices with my friends'; and (5) ICT interest (INTICT, α = 0.79), which refers to the index of six items, such as 'I am really excited discovering new digital devices or applications.' The above focus independent variables, except ICTHOME, were weighted likelihood estimates (WLE) with mean = 0 and standard deviation = 1, and each scale's reliability and validity were established by PISA 2015 (OECD 2016b). A higher score represents a higher extent.

Other variables

First, students' economic, social, and cultural status (ESCS, α = 0.74) was included as a control variable. ESCS is a composite measure of students' socioeconomic status, which is based on three family background measures: parental occupation, parental education, and home possessions (OECD 2016b). Additionally, students' science self-efficacy (SCIEEFF, α = 0.89) was included as a mediator to mediate the relationships between students' ICT interest and science achievement. Like the ICT variables, SCIEEFF is also a WLE measure comprised of eight items to represent students' self-reports of how they would perform on different science tasks. Finally, variable ST004 was adopted to identify students' gender in order to analyze the model for female and male students.

Analysis

First, preliminary analyses for descriptive statistics and correlation were conducted in order to understand the fundamental features of the data. To answer the first research question concerning the relationship between ICT variables and science achievement, the current study employed a path model using LISREL 9.3, which explored the relationship pattern between ICT availability, ICT interest, ICT psychological need satisfactions, and science achievement. The path analysis followed the conceptual framework in Figure 1. In particular, the following are several hypothetical paths on testing the relationships between ICT variables and science achievement. First, students' ICT availability at home and ESCS would impact students' ICT psychological need satisfactions including ICT competence, autonomy, and social relatedness. Second, students' ICT psychological need satisfactions would impact students' interest in doing ICT-related activities. Third, students' ICT interest would impact students' science self-efficacy and, in turn, influence students' science achievement. Finally, students' ESCS, ICT availability, ICT psychological need satisfactions, and ICT interest would have indirect and total effects on students' science achievement.

To answer research question 2a regarding gender differences in ICT variables and students' science achievement, a series of independent sample *t*-tests were conducted to compare ICT variables (ICT availability, ICT psychological need satisfactions, and ICT interest) and science achievement between female and male students.

The above descriptive statistics, correlation, and *t*-test analyses were conducted using the IDB Analyzer. Since PISA used a two-stage sampling method, a final student weight (W_FSTUWT) was applied in the above analysis by using the IDB Analyzer. In addition, the software processed the 10 science PVs, which resulted in one comparable science achievement score for each student.

In addition, to answer question 2b regarding whether there were gender differences in the relationships between ICT variables and students' science achievement, the study split the data into two gender groups. The above path analysis was tested separately for male and female students.

To test the overall fit of the two models (male model and female model), the current study addressed five model fit indices: chi-square statistic (χ^2), root-mean-square error of approximation (RMSEA), normed fit index (NFI), comparative fit index (CFI) and goodness of fit index (GFI). Chi-square statistics has been widely addressed in evaluating model-data-fit. However, it is sensitive to a large sample size, which might lead to significant results and a misinterpretation of a poor fit (Kenny and McCoach 2003). Since the current study has a very large sample size, the study also employed the abovementioned indicators along with the chi-square, to provide an overall trustworthy model-data-fit result. In particular, the following are good model-data-fit criteria for the indicators: RMSEA values should be less than.10 and NFI, CFI, and GFI values should be greater than .90. When the model satisfies the above model-data-fit criteria, the tested direct, indirect and total effects in the model can be trusted.

Results

Table 2 presents the descriptive statistics and correlation results prior to the main path analysis. After listwise deleting the missing cases, 8,352 out of 9,841 students were left in the B-S-J-G (China) dataset. Since 85% of the cases remained in the sample, the number of students in the sample could be accepted. Correlation analysis results demonstrated a statistically significant correlation between the hypothesized variables in the study.

Relationships between ICT variables and science achievement

As shown in Table 3, the path analysis for both females and males revealed acceptable fit statistics. Although the chi-square showed statistically significant results ($p < .01$) due to the large sample size used in this study, all other indicators showed good model-data-fit. Specifically, for the female model, the fit indexes are: χ^2 (1) = 15.00, $p < .01$; RMSEA = 0.058; NFI = 0.998; CFI = 0.999; GFI = 0.999. For the male model, the fit indexes are: χ^2 (1) = 15.24, $p < .01$; RMSEA = 0.055; NFI = 0.998; CFI = 0.999; GFI = 0.999. The results offered empirical evidence that supports the hypothesized model.

Table 2. Means, standard deviations, and correlations.

			Correlations							
Variable	Mean	SD	ESCS	Self-Efficacy	ICT-Home	INT-ICT	AUT-ICT	COMP-ICT	SOIA-ICT	Science Achieve-ment
ESCS	−1.01	1.10	1.00							
Self-efficacy	0.00	1.13	0.24**	1.00						
ICT Home	6.16	2.59	0.60**	0.22**	1.00					
INTICT	−0.35	0.86	0.24**	0.06**	0.22**	1.00				
AUTICT	0.04	0.90	0.27**	0.21**	0.28**	0.50**	1.00			
COMPICT	−0.49	0.78	0.25**	0.18**	0.30**	0.52**	0.62**	1.00		
SOIAICT	0.08	0.83	0.14**	0.18**	0.22**	0.38**	0.51**	0.52**	1.00	
Science Achievement	528.1	99.4	0.44**	0.22**	0.24**	0.17**	0.28**	0.28**	0.03*	1.00

*p <.05
**p <.01
N = 8352 df = 8350
Note: ESCS is students' economic, social and cultural status; ICT Home is ICT availability at home; INTICT is ICT interest; AUTICT is perceived ICT autonomy; COMPICT is perceived ICT competence; SOIAICT is perceived ICT social-relatedness.

Table 3. Model fit statistics of two gender groups.

	Chi-square	RMSEA	NFI	CFI	GFI
Female	15.00 (1), p <.01	0.058	0.998	0.999	0.999
Male	15.24 (1), p <.01	0.055	0.998	0.999	0.999

Note. RMSEA: root mean square error of approximation; NFI: normed fit index; CFI: comparative fit index.

Female model

Figure 2 shows direct effects of exogenous variables in detail, with Table 4 showing indirect and total effects of the female model.

For ICT availability at home, results indicated that there was no statistically significant relationship between female students' ICT availability at home and their science achievement, regardless of the direct, indirect, or total effects. In other words, female students' more or less ICT availability at home is not related to an increase or decrease in students' science achievement, above and beyond the relationships of other variables in the model.

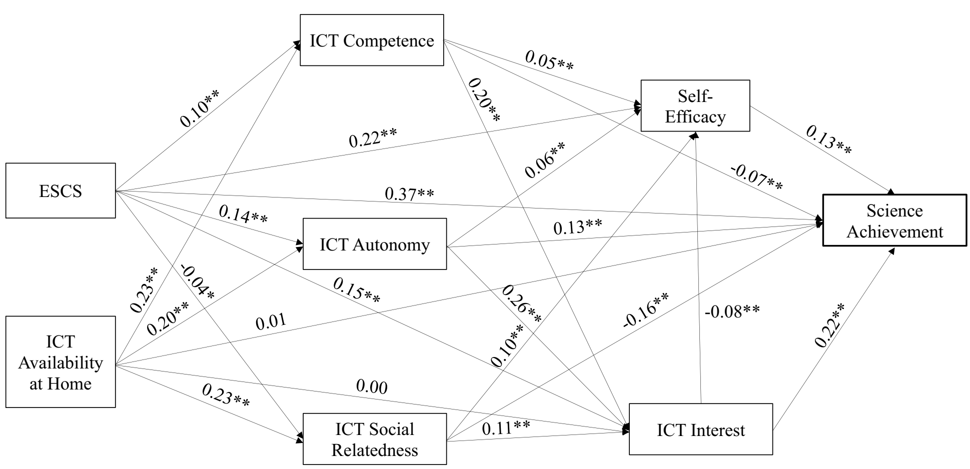

Figure 2. Path analysis results for female model.

Table 4. Direct, indirect, and total effects of female model.

Effect	Direct Effect	Indirect Effect	Total Effect
INTICT → Science	0.22**	−0.01	0.21**
INTICT → Self-efficacy	−0.08**		−0.08**
COMPICT → Science	−0.07**	0.05**	−0.02
COMPICT → INTICT	0.20**		0.20**
AUTICT → Science	0.13**	0.06**	0.19**
AUTICT → INTICT	0.26**		0.26**
SOIAICT → Science	−0.16**	0.04	−0.12**
SOIAICT → INTICT	0.11**		0.11**
Self-efficacy → Science	0.13**		0.13**
ICT Home → Science	0.01	0.00	0.01
ICT Home → INTICT	0.01	0.12**	0.12**
ESCS → Science	0.37**	0.09**	0.46**
ESCS → INTICT	0.15**	0.05**	0.20**
ESCS → Self-efficacy	0.22**	−0.01	0.21**

Note: ESCS is students' economic, social and cultural status; ICT Home is ICT availability at home; INTICT is ICT interest; AUTICT is perceived ICT autonomy; COMPICT is perceived ICT competence; SOIAICT is perceived ICT social-relatedness.

For the three ICT psychological need satisfaction variables, the relationships with science achievement were inconsistent. Female students' ICT competence level had a statistically significant negative direct relationship with science achievement (β_{direct} = −0.07, SE = 0.02, p < .01), but it had a statistically significant positive indirect effect ($\beta_{indirect}$ = 0.05, SE = 0.01, p < .01) and non-significant total effect on students' science achievement. ICT autonomy showed statistically significant direct, indirect, and total effects on students' science achievement (β_{direct} = 0.13, SE = 0.02, p < .01; $\beta_{indirect}$ = 0.06, SE = 0.01, p < .01; β_{total} = 0.19, SE = 0.02, p < .01). Although ICT social-relatedness had a non-significant indirect effect on female students' science achievement via students' ICT interest and science self-efficacy, it showed statistically significant negative direct and total effects on female students' science achievement (β_{direct} = −0.16, SE = 0.02, p < .01; β_{total} = −0.12, SE = 0.02, p < .01). In other words, through the path of ICT interest and science self-efficacy, female students with higher perceived ICT autonomy but lower perceived ICT social-relatedness had better science achievement.

Although ICT interest did not have a statistically significant indirect effect on female students' science achievement via students' science self-efficacy as a mediator, it had statistically significant positive direct and total effects on students' science achievement (β_{direct} = 0.22, SE = 0.02, p < .01; β_{total} = 0.21, SE = 0.02, p < .01). In other words, through the path of science self-efficacy, female students with greater interest in ICT tend to have better science achievement outcomes.

Male model

Figure 3 shows direct effects of exogenous variables in detail, with Table 5 showing indirect and total effects of the male model.

For ICT availability at home, results indicate that male students' ICT availability at home showed statistically significant negative direct and total effects, but a statistically significant positive indirect effect on their science achievement (β_{direct} = −0.12, SE = 0.02, p < .01; $\beta_{indirect}$ = 0.01, SE = 0.01, p < .01; β_{total} = −0.11, SE = 0.02, p < .01). In other words, male students with greater ICT availability at home tend to have lower science achievement, above and beyond the relationships of other variables in the model.

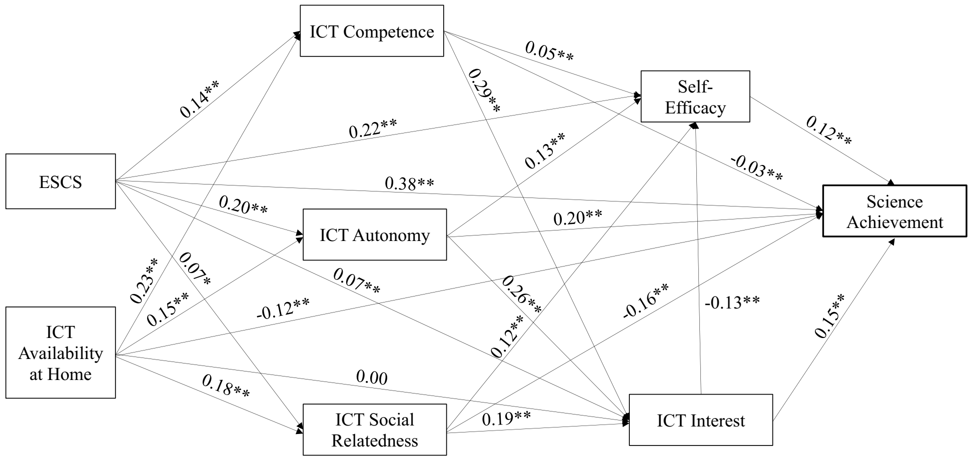

Figure 3. Path analysis results for male model.

Table 5. Direct, indirect, and total effects of male model.

Effect	Direct Effect	Indirect Effect	Total Effect
INTICT → Science	0.15**	−0.02	0.13**
INTICT → Self-efficacy	−0.12**		−0.12**
COMPICT → Science	−0.03	0.05**	0.02
COMPICT → INTICT	0.29**		0.29**
AUTICT → Science	0.20**	0.05**	0.15**
AUTICT → INTICT	0.25**		0.25**
SOIAICT → Science	−0.16**	0.03**	−0.13**
SOIAICT → INTICT	0.09**		0.09**
Self-efficacy → Science	0.12**		0.12**
ICT Home → Science	−0.12**	0.01**	−0.11**
ICT Home → INTICT	−0.03	0.10**	0.07**
ESCS → Science	0.38**	0.07**	0.45**
ESCS → INTICT	0.07**	0.10**	0.17**
ESCS → Self-efficacy	0.21**	0.02**	0.23**

Note: ESCS is students' economic, social and cultural status; ICT Home is ICT availability at home; INTICT is ICT interest; AUTICT is perceived ICT autonomy; COMPICT is perceived ICT competence; SOIAICT is perceived ICT social-relatedness.

For the three ICT psychological need satisfaction variables, the relationships with science achievement were also inconsistent. In particular, male students' ICT competence level had a statistically significant positive indirect relationship with science achievement ($\beta_{indirect}$ = −0.05, SE = 0.01, p < .01), but it non-significant direct effect and total effect on students' science achievement. ICT autonomy showed statistically significant direct, indirect, and total effects on students' science achievement (β_{direct} = 0.20, SE = 0.02, p < .01; $\beta_{indirect}$ = 0.05, SE = 0.01, p < .01; β_{total} = 0.15, SE = 0.02, p < .01). Although ICT social-relatedness had a non-significant indirect effect on male students' science achievement via students' ICT interest and science self-efficacy, it had statistically significant negative direct and total effects on male students' science achievement (β_{direct} = −0.16, SE = 0.02, p < .01; β_{total} = −0.13, SE = 0.02, p < .01). In other words, through the path of ICT interest and science self-efficacy, male students with higher perceived ICT autonomy, but lower perceived ICT social-relatedness tend to have better science achievement outcomes.

Although ICT interest had a non-significant indirect effect on male students' science achievement via students' science self-efficacy as a mediator, it had statistically significant positive direct and total effects on students' science achievement (β_{direct} = 0.15, SE = 0.02, $p < .01$; β_{total} = 0.13, SE = 0.02, $p < .01$). That is, through the path of science self-efficacy, male students with greater interest in ICT tend to have better science achievement outcomes.

Other relationships

For both female and male students, ICT competence level, ICT autonomy, and ICT social-relatedness variables all showed a statistically significant positive direct relationship with an ICT interest.

Gender gap across the relationships

Table 6 shows independent *t*-test results to explore the mean differences in terms of ICT availability, three ICT motivational behavior variables, ICT interest, and science achievement between female and male students. Compared with male students, female students had significantly lower ICT availability at home ($t = 3.75$, $p < .01$), lower ICT competence ($t = 11.29$, $p < .01$), lower ICT autonomy ($t = 13.05$, $p < .01$), lower ICT social relatedness ($t = 12.07$, $p < .01$), lower ICT interest ($t = 11.04$, $p < .01$), and lower science achievement ($t = 4.43$, $p < .01$). In other words, male students had higher performances in terms of both ICT variables and science achievement as compared with their female peers.

Comparing the results between the female and male models, females' and males' relationships between ICT variables and students' science achievement were generally the same, except for one variable, which was students' ICT availability at home. The results indicate that for female students, there was no statistically significant relationship between female students' ICT availability and their science achievement. However, male students' ICT availability had statistically significant negative direct and total effects on their science achievement. In other words, while female students' availability of ICT at home had no influence on their science achievement, male students' with less ICT

Table 6. *T*-test comparing ICT use, ICT interest, ICT psychological needs, and science achievement between male and female students in B-J-S-G.

	Female		Male		t-test Results			
	Mean (SD)	S.E.	Mean (SD)	S.E.	t-value	df	SE	Effect Size
ICT Home	5.82 (2.60)	0.09	6.27 (2.67)	0.08	3.75**	9048	0.12	0.18
ICT Interest	−0.50 (1.35)	0.02	−0.26 (0.7)	0.01	11.04**	9601	0.02	0.22
ICT Competence	−0.67 (0.67)	0.02	−0.35 (0.84)	0.02	11.29**	9599	0.03	0.42
ICT Autonomy	−0.18 (0.82)	0.02	0.19 (0.93)	0.02	13.05**	9603	0.03	0.42
ICT Social Relatedness	−0.11 (0.73)	0.02	0.24 (0.88)	0.02	12.70**	9590	0.03	0.43
Science Achievement	512.79 (101.4)	1.52	522.15 (104.9)	1.46	4.43**	9839	2.11	0.10

**significance level at.01
Note: Effect Sizes were calculated by Cohen's d.

availability at home tend to perform better in science achievement than male students with more ICT availability.

Discussion

ICT availability and science achievement

The negative direct effect of male students' ICT availability on science achievement and no relationship of ICT availability on female students' science achievement are consistent with prior studies (Lee and Wu 2012; Luu and Freeman 2010). However, our study also revealed that there was a significant positive indirect effect of ICT availability on science achievement through the path of other variables, including ICT psychological need satisfactions. In addition, the magnitude of the negative total effect of ICT availability decreased through the path, suggesting that the relationship between ICT availability and science achievement might be mediated through the path of other ICT-related variables.

There have been many debates on the relationships between ICT availability and student achievement (Erdogdu and Erdogdu 2015; Kim 2018a) and on technology investment (Oppenheimer 2004). Moreover, scholars have also indicated that there is not a simple direct relationship between ICT availability and student achievement, given the nature of technology (Cuban 1986; Oppenheimer 2004; Waight and Abd-El-Khalick 2012). In other words, when exploring the impact of ICT availability on science achievement, other ICT use variables are also involved, such as the purpose for which ICT is used and how long and how frequently it is used (Cheema and Zhang 2013; Hu et al. 2018; Luu and Freeman 2010; Zhang and Liu 2016).

Our findings add empirical evidence to these arguments given that the association between ICT availability and student achievement differs depending on the ICT variables taken into consideration. However, the path detailing the relationships between ICT availability and students' achievement is unknown. Future research should engage path analysis and in-depth qualitative research methods to further discern the role and relationships of ICT variables, such as ICT use frequency, quality, purpose, psychological need satisfactions, interest, and other variables that have not been considered. Through specifying these relationships, clear and detailed guidelines can be offered and considered towards investment, implementation, and enactment of ICT in education.

ICT psychological need satisfactions and science achievement

Previous research indicated that three innate psychological need satisfactions – competence, autonomy, and social-relatedness (Deci and Ryan 2000) – predict learners' interest in doing relevant tasks (Krapp 2002; Minnaert 2007). Results from this study add evidence to these relationships in the area of ICT. That is, ICT psychological need satisfactions predict students' interest in doing ICT tasks, which suggests that students' interest in ICT can be cultivated through the support of their ICT psychological need satisfactions.

Results from this study also revealed that the relationships between the three psychological need satisfactions and science achievement varied. First, our findings indicated a statistically insignificant total effect of ICT competence on student science achievement, which is not consistent with previous studies that showed positive relationships between

ICT competence and student science achievement (Luu and Freeman 2010; Hu et al. 2018; Zhang and Liu 2016). However, our study shows that the indirect effect between ICT competence and science achievement was significantly positive. That is, the positive effect of ICT competence on students' science achievement was fully mediated through the path of ICT interest. Thus, it might be that a student who has a strong belief in their ability to master the use of ICT tends to have greater interest in ICT use, which might improve the quality of ICT use when engaging in science-related activities involving ICT. In this way, educators should encourage the development of students' positive beliefs in their ICT abilities.

Second, results from this study showed that ICT autonomy has a positive relationship with science achievement, which is consistent with prior studies (Hu et al. 2018; Areepattamannil and Santos 2019). Previous research has suggested that ICT autonomy is more strongly related to science dispositions as compared with ICT competence (Areepattamannil and Santos 2019). Our study demonstrates that this stronger relationship also exists in science achievement. In other words, with respect to facilitating their science achievement, students' perceptions of personal independence in competently using ICT is more important than their belief in their ICT ability. Thus, the stronger relationship suggests that when engaging in science-related activities involving ICT, students' self-organization and personal independence are important considerations.

In contrast, ICT social-relatedness was found to be negatively related to science achievement, which is also consistent with previous research (Hu et al. 2018). One possible reason for this negative association might be that students engage in social interactions that hinder or have no relationship with academic learning. Thus, it suggested that students' positive feelings of ICT connectedness to others might have a negative impact on their learning performance, when the ICT activity was not for learning purpose.

ICT interest and science achievement

Studies examining ICT and students' learning have primarily focused on students' ICT use, literacy, and skills (e.g., Areepattamannil and Khine 2017; Skryabin et al. 2015; Vekiri and Chronaki 2008) but have not attended to students' ICT motivation and interest. However, little is known regarding the mechanism behind the relationship between ICT interest and students' achievement. Our findings indicated that developing students' ICT interest might be an effective way to promote students' ICT behavior, which is consistent with previous research (Hu et al. 2018). It is also noteworthy that the magnitude of the effect of ICT interest was large – even larger than the effect of students' science self-efficacy, a well-known factor that impacts science achievement. Our study results encourage facilitation of students' ICT interests in order to promote their science achievement, although the reason behind the large impact of ICT interest on science achievement requires further exploration.

Gender differences in ICT and science achievement

This study adds evidence to previous studies that revealed an ICT gender gap (Drabowicz 2014). Upon closer interrogation of the gender differences in ICT, our study suggests that male students had better ICT competence, which is consistent with previous studies (Zhang and Liu 2016). However, studies that indicate a gender-balanced picture considered ICT usage time, attitude, and self-efficacy rather than ICT psychological factors (Gumus and Atalmis 2011; Luu and Freeman 2010; Pamuk and Peker 2009; Tsai and Tsai 2010). Since our study revealed that the ICT psychological need satisfactions and interest factors also are associated with students' achievement, the gender differences among these ICT psychological need satisfactions should also be given further attention.

Regarding science achievement, this study's findings were consistent with previous studies, which showed greater science achievement among male students (Chi et al. 2018; Miyake et al. 2010; Quinn and Cooc 2015). Thus, with increased calls for using ICT in science learning, will the ICT gender gap further widen the gap between male and female students with respect to science achievement? When integrating ICT during science instruction, it is possible that, as compared with females, male students with greater ICT psychological need satisfactions and interest would benefit more than their female peers. If we do not consider the ICT gender inequities when using ICT in education, the gap in science learning might also be exacerbated.

Further, prior studies indicate that ICT gender differences tend to disappear when females are given similar access to computers and instructional opportunities as males (Papastergiou and Solomonidou 2005). Our study demonstrates that ICT autonomy and interest also had statistically significant positive relationships with both female and male students' science achievement, and that, while ICT availability negatively impacts male students, it does not hinder science achievement for female students. As such, one major suggestion is to provide greater ICT access for female students and to encourage them to use ICT more frequently, in order to facilitate their ICT autonomy and interest. In this way, not only would a gender gap in ICT potentially be reduced but the difference in science achievement between male and female students might also be minimized. Possible moderation relationships of gender on students' ICT use and achievement are also suggested for future research, to better understand and address the gender inequities, with respect to both ICT and science achievement.

Conclusion and implications

The current study contributes to the field of technology in science education in three ways: (1) the study revealed possible paths from ICT availability to science achievement, and offered an in-depth understanding on indirect associations and interrelationships among factors; (2) the study explored how ICT psychological need satisfactions and interests were related to science achievement, thereby responding to a previous call for such research based on established psychological theories (Hu et al. 2018); (3) the study clarified gender differences in ICT, science achievement, and their relationships, and provided practical insights to help close the gender gap in both ICT and science education.

The above findings have implications for both teachers and future researchers. The findings remind teachers to take students' psychological needs into consideration when implementing ICT in student learning. Special attention should be drawn to female student science learning when teachers implement ICT in their instructional design. Researchers could extend the model of the current study by studying other possible paths, especially the paths involving the quality of ICT use. Future research is suggested to investigate reasons for the strong relationship between ICT interest and science achievement, and reexamine the inconsistent results on the relationships between the three ICT psychological need satisfactions and science achievement. Given that this study was based on data from one country, specifically China, the above findings may not be applicable to other countries, particularly developed countries. Thus, future research is needed to replicate this study using data from other countries, particularly developed countries.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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