Chinese/English Journal of Educational Measurement and Evaluation | 教育测量与评估双语季刊

Volume 3 | Issue 3 Article 3

2022

Examining the Impact of Students' Familiarity with Information and Communications Technology on Education Equity Using Data from Students in Four Provinces and Cities in China

Dengying Cai
University of Macau

Kwok Cheung Cheung
University of Macau

Pou Seong Sit
University of Macau

Man Kai Ieong
University of Macau

Recommended Citation

Cai, Dengying; Cheung, Kwok Cheung; Sit, Pou Seong; and Ieong, Man Kai (2022) "Examining the Impact of Students' Familiarity with Information and Communications Technology on Education Equity Using Data from Students in Four Provinces and Cities in China," *Chinese/English Journal of Educational Measurement and Evaluation | 教育测量与评估双语季刊*: Vol. 3: Iss. 3, Article 3.
Available at: https://www.ce-jeme.org/journal/vol3/iss3/3

Examining the Impact of Students' Familiarity with Information and Communications Technology on Education Equity Using Data from Students in Four Provinces and Cities in China

Dengying Cai, Kwok Cheung Cheung, Pou Seong Sit, and Man Kai Ieong

Faculty of Education, University of Macau

Abstract

Using mediation analyses, this study analyzes PISA 2015 scientific literacy computerized assessment data collected from students in Beijing, Shanghai, Jiangsu and Guangdong, examines the relationship between students' familiarity with information and communications technology and educational equity, and offers recommendations based on results of the study. Findings of the study provides empirical support for reducing digital education inequity and narrowing the academic literacy performance differences between students of different socioeconomic and cultural status.

Keywords

Equity in education; Information and communications technology; Socioeconomic status; Scientific literacy; PISA

Marking a new era, information and communication technology (ICT) overcomes the limitations of physical spaces and is ubiquitous in aspects of daily life and learning. It also presents a potential way to reduce educational inequity and improve the effectiveness of basic education, hence drawing the attention of Chinese education policy makers and educational researchers in recent years. Since the beginning of the 21st century, China's basic education has been undergoing education informatization. Issued by the Ministry of Education of China in 2016, the 13th Five-Year Plan for Education Informatization stated that "prioritizing education informatization to promote equity in education" would be the main task during period of the 13th Five-Year Plan, and "comprehensively improving education quality, promoting educational equity at a higher level, and accelerating the process of education modernization" would be the focus of education informatization. The plan also pointed out the development trajectory and objectives of China's education informatization in the next five years. While numerous studies have explored informatization and education quality in China, there is a paucity of empirical research examining the impact of web-based ICT on educational equity. With data collected by the Programme for International Student Assessment (PISA), this study analyzes PISA 2015 scientific literacy assessment data, explores the use of ICT for reducing differences in scientific literacy performance between students in urban and rural areas and students of different economic, social and cultural status (ESCS), and recommends measures for tackling inequities in education.

1 Literature Review

1.1 Research on ICT and Education Equity

Literature review of international large-scale assessment programs revealed a slight difference in researchers' understanding of educational equity, which was shaped by the particularities of countries' circumstances and times (Organization for Economic Cooperation and Development [OECD], 2001, 2016, 2018). This study adopts PISA's definition of educational equity, that is, treating every student fairly so that academic achievement differences amongst students are not determined by their ESCS (OECD, 2016, 2018). In terms of the operational definition, the strength and slope of the ESCS-gradient line can reflect levels of educational equity of a country/economy (OECD, 2016). The former indicates the explanatory power of ESCS with respect to literacy performance. The latter indicates the corresponding increment of literacy performance, as defined by the regression equation, for each unit increase in ESCS. Therefore, mitigating such magnitude and slope may be seen as a way to improve

Contact: Pou Seong Sit, Faculty of Education, University of Macau, Macau 999078, China, pssit@um.edu.mo.
Translator: Tianying Feng, 300 Charles E. Young Drive North, Los Angeles, CA 90095, tfeng@cresst.org.

educational equity. For example, J. Chen (2015) and Ieong (2015) respectively found that parents' school choices and students' self-regulatory learning abilities mediated the impact of ESCS on literacy performance, and the inclusion of mediators resulted in a reduced standardized regression coefficient of ESCS and consequently a statistically reduced slope of the gradient line.

As an important criterion for evaluating the development of education, educational equity is also a "touchstone" for validating the achievements of education development. According to the PISA 2015 results, the average scientific literacy performance of students in Beijing, Shanghai, Jiangsu, and Guangdong (hereinafter referred to as the four provinces and cities in China) was 518 points. This value ranked 10th among all participating countries and economies and was higher than the OECD average of 493 points. However, ESCS had an explanatory power of 18.5% for scientific literacy, which was 6% higher than the OECD average of 12.5%. As seen from such results, the disparity in academic performance between students of different ESCS in the four provinces and cities in China was relatively large, and the four regions were among the economies that lacked educational equity (OECD, 2016, 2017c).

With the rapid development of ICT, "technology revolutionizes education" has become a main theme of education development. The impact of ICT on equity in education has also attracted the attention of scholars in mainland China. For example, since 2012, PISA has gradually transitioned from paper-and-pencil based testing to computer-based testing. C. Chen and Gu (2017) used PISA 2012 Shanghai data to explore the impact of ICT on educational equity and found a relationship among web-based learning preferences, ESCS, and academic performance: For students from low-socioeconomic (SES) families, web-based learning could reduce ESCS-induced performance gaps if students developed a preference for learning through the Internet. Xiao and Hu (2019) explored the moderating effect of ICT on the relationship between ESCS and reading literacy performance of students in the four provinces and cities in China using PISA 2015 data. They found that students' uses of ICT for schoolwork and entertainment moderated the relationship between ESCS and reading literacy performance, suggesting that more frequent use of ICT for schoolwork or entertainment could reduce differences in reading literacy performance between students of different ESCS.

In the case of international comparative research, Chiao and Chiu (2018) analyzed PISA 2012 data collected from six Asian countries and economies. Their results showed that for students of different ESCS, their uses of ICT for information retrieval and social interaction would widen the academic performance gap; students with lower ESCS used ICT less for information retrieval and more for social interaction. Michael and Richard (2019) used PISA 2015 data to study seven countries and economies in East Asia; their results refuted the impact of ICT use on educational equity.

In summary, there have been mixed findings and controversies regarding the impact of ICT on educational equity, and no extant studies that used mediation analysis to explore measures for improving educational equity in mainland China. Therefore, with PISA's definition of educational equity, this study selected data from PISA 2015 that focused on evaluating scientific literacy. The study then examined whether variables/indicators of ICT familiarity mediated the impact of ESCS on scientific literacy performance for students in the four Chinese provinces and cities, so as to understand the impact of ICT on educational equity and ways to promote such equity in China.

1.2 Research on ICT Familiarity

The computer familiarity questionnaire of PISA 2015 focused on three dimensions (OECD, 2017a): ICT availability, student use of ICT for performing ICT-based tasks (denoted as ICT use in subsequent discussions), and ICT engagement. Specifically, Zylka et al. (2015) argued that constructs of ICT engagement should be rooted in Self-determination Theory, which consisted of three sub-dimensions: self-concept related to the use of ICT, daily and social exposure to ICT, and ICT-related interest. The sub-dimensions were closely related to the concept of competence of Self-determination Theory (see Deci et al., 1991), specifically to the idea that individuals' confidence in their own ICT competencies and dispositions towards ICT can enhance their intrinsic motivation. Ryan and Deci (2000) also pointed out that intrinsic motivation could promote high-quality learning and creativity, and lead individuals to perform activities that would bring joy and internal satisfaction, during which the individuals would also initiate, adjust, and monitor their progresses in a self-determined manner. Building on results of Zylka et al. (2015), Kunina-Habenicht and Goldhammer (2020) further incorporated the autonomy dimension in Self-determination Theory. They conceptualized constructs of ICT engagement as consisting of four factors—interest in ICT, student perceived ICT competency, student perceived autonomy around ICT use, and inclusion of ICT as a topic in social interactions, and examined construct validity via structural equation modeling. This study conceptualizes ICT engagement following the theoretical framework of Kunina-Habenicht and Goldhammer (2020).

In terms of research on ICT availability, ICT use, and ICT engagement, Arpaci et al. (2021) argued that the former two could explain the variation in scientific literacy. However, after considering the level of ICT development in various regions, they found that the explanatory power of variables of interest was lower in regions with developed ICT than in regions with less developed ICT. Zhu and Li (2022) analyzed the Hong Kong PISA assessment data and found that both the use of ICT at school and the use of ICT related to schoolwork at home were significantly related to literacy performance, but the former was negatively correlated with literacy performance. Kunina-Habenicht and Goldhammer (2020) established the constructs of ICT engagement and explored their relationship with literacy performance, using PISA 2015 data from Sweden and Germany. They found that in addition to students' interest in ICT, boys consistently scored higher on ICT engagement indicators than girls, and their performance on the indicator of including ICT as a topic in social interactions was weakly correlated with reading literacy. Odell et al. (2020) reviewed 25 ICT-related studies. They found that most of the ICT-related variables had inconsistent effects on academic performance and the directions of such effects also varied, although moderate use of ICT seemed to be more beneficial to students' academic performance. Odell et al. also indicated that although there were not many studies on autonomy around ICT use, interest in ICT, and ICT as a topic in social interactions, these variables could positively predict students' performance in mathematics and science.

2 Research Design

2.1 Sample Selection

The raw data used by this study were taken from the public database hosted on the PISA official website (http://www.oecd.org/pisa/), which covered assessment and questionnaire data from 519,334 15-year-old middle school students from 72 countries and economies, who participated in PISA 2015. Researchers of the study extracted data from 9,841 students in the four provinces and cities in China for analysis.

2.2 Variable Selection

Based on the literature review, this study used the ICT familiarity questionnaire of PISA 2015 as the main research instrument consisting of three dimensions and a total of nine variables: (1) ICT availability, including two variables about "ICT availability at home (ICTHOME)" and "ICT availability at school (ICTSCH)"; (2) ICT use, including three variables about "ICT use for entertainment outside school (ENTUSE)", "schoolwork-related ICT use at home (HOMESCH)," and "ICT use at school (USESCH)"; (3) ICT engagement, including four variables about "student interest in ICT (INTICT)," "student perceived ICT competency (COMPICT)," "student perceived autonomy around ICT use (AUTICT)," and "inclusion of ICT as a topic in social interactions (SOIAICT)."

In addition, the study included students' digital scientific literacy performance in PISA 2015 as the dependent variable. The study also included background variables (gender, family ESCS) as the control and independent variables in the analyses of mediation effects. The variables of interest and their reliabilities are shown in Table 1.

2.3 Research Method

The study used SPSS 24.0, IDB Analyzer 4.0.36, Product Confidence Limits for Indirect Effect (PRODCLIN) and Excel as the statistical analysis tools. Using PISA 2015 student questionnaire and scientific literacy assessment results as the raw data, the study treated ESCS as the independent variable, ICT familiarity (including 9 indicators of ICT availability, ICT use, and ICT engagement) as a mediating variable, scientific literacy performance as the dependent variable, and student gender as a control variable. The relationship between ICT familiarity and educational equity was analyzed through mediation analysis. Because the data were gathered from PISA large-scale assessment database, the analytic process must follow recommendations of OECD (2009) and OECD (2017b). The recommendations included the application of weighting to student data and the use of replicate weights to properly compute sampling error. In addition to computing sampling error, analyses involving plausible values should also compute measurement error and means of the statistics. For example, when examining the correlation between PISA 2015 scientific literacy and an ICT-related indicator, weighting is required. The correlation between every set of scientific literacy plausible values (10 sets in total) and

Table 1
PISA 2015 Student Background and ICT Familiarity Variables Used in the Study

Dimension	Variable description	Variable name	Reliability (Cronbach's Alpha)
Student background	Gender: 1=Female; 0=Male.	ST004D01T	–
	Family ESCS: Constructed according to the three indicators: parental highest occupational status, highest educational attainment, and household possessions.	ESCS	0.74
ICT availability	(1) ICT availability at home.	ICTHOME	0.77
	(2) ICT availability at school.	ICTSCH	0.82
ICT use	(3) ICT use for entertainment outside school.	ENTUSE	0.89
	(4) Schoolwork-related ICT use at home.	HOMESCH	0.92
	(5) ICT use at school.	USESCH	0.87
ICT engagement	(6) Student interest in ICT.	INTICT	0.79
	(7) Student perceived ICT competency.	COMPICT	0.80
	(8) Student perceived autonomy around ICT use.	AUTICT	0.89
	(9) Inclusion of ICT as a topic in social interactions.	SOIAICT	0.84

Note. Values of the two variables of ICT availability were computed by summing item scores across the relevant items. Values of variables of ICT use and ICT engagement were IRT-scaled scores, where the mean was fixed at 0 and the standard deviation was fixed at 1 among OECD participating countries, see OECD (2017b) for details. The Appendix presents questionnaire items associated with each ICT familiarity variable; for more information on the content of variables and IRT parameters, please refer to OECD (2017b).

the ICT indicator then needs to be computed to obtain an estimate per set. The mean of all 10 estimates is then computed while computing sampling, measurement, and total errors to obtain the finalized results. For details on the theory, procedure, and concepts of replicate weights and plausible values, please refer to OECD (2009, pp. 47-130).

3 Analysis of Mediation Effects of ICT Familiarity Indicators

Based on Baron and Kenny (1986) method for testing mediational hypotheses, the study calculated a, b, c, and c' in four steps shown in Figure 1 to test the mediation effect of each indicator ($= ab = c - c'$).

After a mediation effect is detected using the Baron and Kenny (1986) method, it becomes also necessary to check whether its strength is statistically significant. The study referred to methods used in Mak (2013), using tests of Sobel (1982) and PRODCLIN (MacKinnon & Fritz, 2007) to examine the significance of each mediation effect ($p <$ .05) and test the hypothesis of whether differences in the scientific literacy performance of 15-year-old middle school students with different ESCS in four provinces and cities in China could be explained by the mediators.

3.1 Identification of Potential Mediators

Before conducting mediation analyses, this study first investigated the association between each of the ICT familiarity variables (or indicators) and scientific literacy, as a basis for checking whether ICT familiarity would explain differences in scientific literacy among students of different ESCS. Table 2 presents the correlations between each indicator of ICT familiarity and student scientific literacy.

According to the correlations between ICT familiarity indicators and scientific literacy, the two indicators—ICT use for entertainment outside school (ENTUSE) and schoolwork-related ICT use at home (HOMESCH) were not significantly related to scientific literacy performance. Therefore, the study excluded the two indicators from subsequent mediation analyses and only tested the remaining seven indicators that may be potential mediators. Note that ICT use at school (USESCH) was negatively correlated with scientific literacy performance, consistent with findings of Zhu and Li (2022) who analyzed PISA data from students in Hong Kong. One possible explanation is related to the purpose and frequency of ICT uses at school. For example, the ICT questionnaire data of PISA 2015 showed that the proportion of students in the four provinces and cities, who used ICT devices for "Chatting online at school" (26.8% reported "at least once or twice a week") was higher compared to student responses to other learning-related ICT items in the questionnaire.

3.2 Analysis of Mediation Effects of ICT Familiarity Indicators on Students' ESCS and Scientific Literacy Performance

Based on the aforementioned research hypothesis, the study then analyzed each of the seven indicators that targeted three ICT-related dimensions: ICT availability, ICT use, and ICT engagement. The analysis results are shown in Tables 3–9.

Results from analyzing the mediating effects of three sets of indicators for ICT availability, ICT use, and ICT engagement showed that four indicators mediated the impact of ESCS on students' scientific literacy performance. Along with the results of regression analyses, the findings were as follows:

(1) In terms of ICT availability, it was found that after adding the indicator of ICT availability at home (ICTHOME), the standardized direct effect of ESCS on scientific literacy did not decrease, signaling a failed mediation test of Baron and Kenny (1986). The ICT availability at school (ICTSCH) partially mediated the impact of ESCS on scientific literacy performance. The researchers of the study believed that because students with higher ESCS were more likely to attend schools with better ICT facilities and learn through school-supplied ICT devices, the average scientific literacy scores of students with higher ESCS would be generally higher than that of students with lower ESCS.

(2) In terms of ICT use, no mediating effect was detected for the three indicators associated with ICT use: ICT use for entertainment outside school (ENTICT), schoolwork-related ICT use at home (HOMESCH), and ICT use at school (USESCH). The former two were not significantly correlated with ESCS. The third indicator, ICT use at school (USESCH), failed to pass Step 1 of the Baron and Kenny (1986) test. That is, after controlling for background variables, the coefficient of regressing ESCS on this indicator was not statistically significant.

(3) In terms of ICT engagement, in addition to the indicator "Inclusion of ICT as a topic in social interactions (SOIAICT)," which was not used as a mediator due to its suppressing effect, the other three indicators—student interest in ICT (INTICT), student

Figure 1
Illustrated Mediation Effect

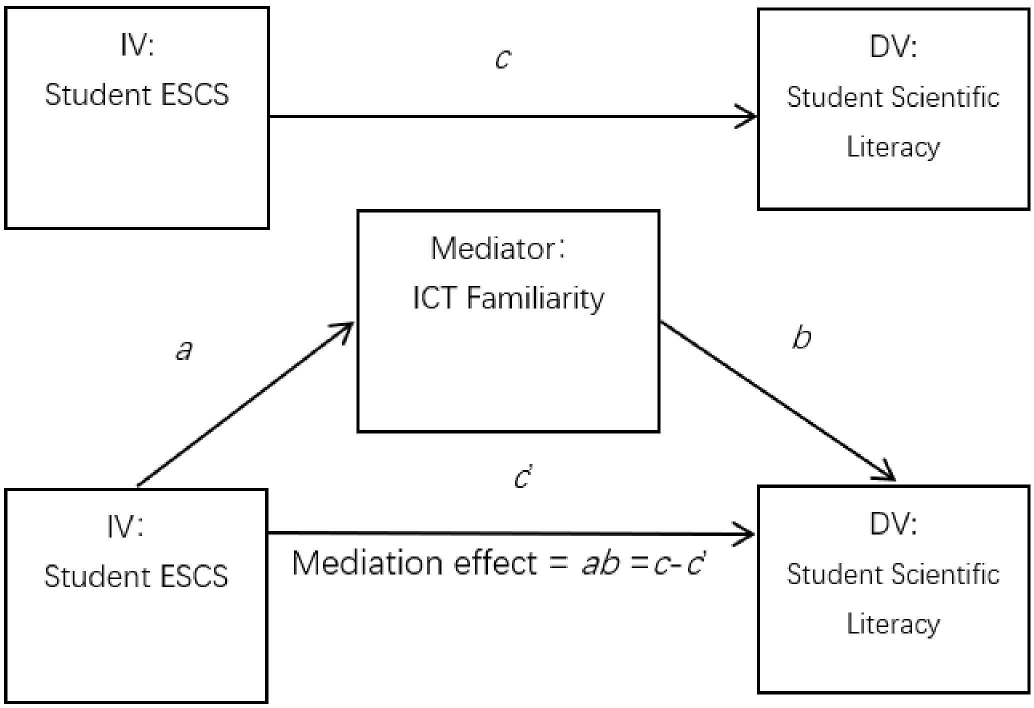


Table 2
Correlations Between ICT Familiarity Indicators and Student Scientific Literacy Performance

Variable	ICT familiarity								
	ICT availability		ICT use			ICT engagement			
	1	2	3	4	5	6	7	8	9
1. ICTHOME	1								
2. ICTSCH	0.341*	1							
3. ENTUSE	0.282*	0.094*	1						
4. HOMESCH	0.313*	0.207*	0.462*	1					
5. USESCH	0.146*	0.159*	0.296*	0.416*	1				
6. INTICT	0.219*	0.065*	0.346*	0.198*	0.117*	1			
7. COMPICT	0.302*	0.110*	0.324*	0.256*	0.152*	0.491*	1		
8. AUTICT	0.273*	0.076*	0.340*	0.246*	0.110*	0.497*	0.616*	1	
9. SOIAICT	0.223*	0.106*	0.326*	0.309*	0.205*	0.377*	0.521*	0.514*	1
Scientific literacy	0.239*	0.142*	-0.009	0.038	-0.159*	0.269*	0.160*	0.264*	0.025*

$^{*}p < .05$.

perceived ICT competency (COMPICT), and student perceived autonomy around ICT use (AUTICT)—were found to be partial mediators explaining part of the differences in scientific literacy performance among students of different ESCS.

3.2.1 ICT Availability

Table 3
Mediation Analysis: ICT Availability at Home (ICTHOME) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on ICTHOME	1.419*	0.031	0.594*	0.016	0.359
Equation 2					
Impact of ESCS and	41.581*	2.484	0.452*	0.028	0.193
ICTHOME on scientific literacy	-0.994	0.772	-0.026	0.020	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. $*p < .05$.

Table 4
Mediation Analysis: ICT Availability at School (ICTSCH) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on ICTSCH	0.629*	0.055	0.235*	0.019	0.055
Equation 2					
Impact of ESCS and	39.491*	2.597	0.425*	0.029	0.196
ICTSCH on scientific literacy	1.834*	0.581	0.053*	0.017	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. $*p < .05$.

3.2.2 ICT Use

Table 5
Mediation Analysis: ICT Use at School (USESCH) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on USESCH	0.022	0.015	0.025	0.017	0.003
Equation 2					
Impact of ESCS and	39.701*	2.508	0.428*	0.028	0.211
USESCH on scientific literacy	-18.618*	2.168	-0.173*	0.022	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. *$p < .05$.

3.2.3 ICT Engagement

Table 6
Mediation Analysis: Student Interest in ICT (INTICT) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on INTICT	0.193*	0.010	0.245*	0.013	0.080
Equation 2					
Impact of ESCS and	34.989*	2.422	0.378*	0.027	0.214
INTICT on scientific literacy	22.078*	1.613	0.188*	0.012	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. *$p < .05$.

Table 7

Mediation Analysis: Student Perceived ICT Competency (COMPICT) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on COMPICT	0.177*	0.010	0.248*	0.015	0.104
Equation 2					
Impact of ESCS and	37.957*	2.480	0.411*	0.028	0.186
COMPICT on scientific literacy	7.583*	1.948	0.059*	0.015	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. *$p < .05$.

Table 8

Mediation Analysis: Student Perceived Autonomy Around ICT Use (AUTICT) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on AUTICT	0.224*	0.011	0.272*	0.015	0.115
Equation 2					
Impact of ESCS and	34.904*	2.348	0.378*	0.027	0.209
AUTICT on scientific literacy	19.573*	1.560	0.174*	0.013	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. *$p < .05$.

Table 9

Mediating Analysis: Inclusion of ICT as a Topic in Social Interactions (SOIAICT) Regression Analysis Results

	Unstandardized		Standardized		R^2
	B	SE_B	β	SE_β	
Equation 1					
Impact of ESCS on SOIAICT	0.098*	0.013	0.130*	0.017	0.062
Equation 2					
Impact of ESCS and	39.488*	2.502	0.427*	0.028	0.182
SOIAICT on scientific literacy	-3.100*	1.404	-0.025*	0.012	
Equation 3 (baseline model)					
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028	0.186

Note. The above Equations 1-3 controlled for the influence of student gender. *$p < .05$.

Furthermore, among the above four mediators, two—student interest in ICT (INTICT) and student perceived autonomy around ICT use (AUTICT)—had the greatest explanatory power with respect to differences in students' scientific literacy scores. After including the two indicators, the regression coefficient of ESCS decreased from 40.3 to 35.0 and 34.9, respectively. Such decreases were 13.2% and 13.4% of the original regression coefficient estimates, respectively, indicating that students' ICT interest and perceived ICT autonomy could explain part of ESCS-induced differences in scientific literacy. In addition, it can be seen from Table 6 and Table 8 that the higher the ESCS of the students, the greater their interest in ICT and the perceived ICT autonomy may be, and the higher the scores for these two indicators, the better the scientific literacy performance. The indicator that had the second greatest explanatory power was student perceived ICT competency (COMPICT). The inclusion of this indicator resulted in a decrease in the estimated coefficient of ESCS from 40.3 to 38.0, suggesting that student perceived ICT competency could partially explain ESCS-induced differences in scientific literacy. According to Table 7, the higher the ESCS of students, the greater their perceived ICT competency may be. Also, the higher the score for this indicator, the better the performance of scientific literacy.

3.3 Analysis of Strengths of Mediation Effects

After the preliminary tests of mediation effects, it is necessary to test the strength of such effects. The study referred to methods used in Mak (2013), using the Sobel test and PRODCLIN to test the significance of each mediation effect ($p < .05$). Based on results in Table 10, all four mediators passed the significance tests.

3.4 Full Mediation Analysis

In order to further explore the maximum explanatory power of the above four mediators with respect to scientific literacy, the study fitted a full multiple regression model. Results from this model revealed that the indicator, student perceived ICT competency (COMPICT) had a collinear relationship with other variables. That is, once added to the full regression model with other variables, its standardized independent effect became negative (-0.106). Therefore, the analysis excluded the indicator of COMPICT, yielding the finalized full model (see Table 11).

Based on the results in Table 11, after controlling the influence of student gender, ICT availability at school (ICTSCH), student interest in ICT (INTICT), and student perceived autonomy around ICT use (AUTICT) all passed the test of independent effect and test of significance. After adding the three mediators, the standardized estimated coefficient of ESCS on students' scientific literacy performance decreased from 0.429 to 0.357. The amount of decrease, 0.072, was the partial mediation effect, indicating that ESCS not only directly affected students' scientific literacy performance but also indirectly affected literacy performance through the mediators. With PISA's operationalized definition of educational equity, the slope of the ESCS gradient line decreased (as shown in Figure 2) with the mediation effects, statistically showing the effects of related variables on improving educational equity.

Moreover, results presented in Table 11 showed that if the ICT availability at school (ICTSCH) indicator increased by 1 unit, the student scientific literacy score would increase by 1.5 points. If the ICT interest indicator (INTICT) increased by 1 unit, the student scientific literacy score would increase by 16.1 points; such an increase was about half of a school grade level. Also, if the indicator of student perceived autonomy around ICT use (AUTICT) increased by 1 unit, the student scientific literacy score would increase by 12.1 points. The results together suggest that the aforementioned variables help improve students' literacy performance and the quality of education.

4 Discussion and Recommendations

Based on PISA's definition and framework of educational equity (OECD, 2016, 2018), this study examined ways to improve equity in education, and particularly, ways to mitigate the impact of ESCS on literacy performance. Specifically, the study analyzed PISA 2015 scientific literacy assessment data using mediation analyses to investigate the relationship among ICT familiarity (including the three sub-dimensions: ICT availability, ICT use and ICT engagement), ESCS, and scientific literacy of students in four provinces and cities in China. The study found that three indicators—ICT availability at school (ICTSCH), student interest in ICT (INTICT), and student perceived autonomy around ICT use (AUTICT)—mediated the impact of ESCS on scientific literacy. These indicators are capable of explaining the differences in scientific literacy performance among students of different ESCS and are of great importance to improving educational equity defined by PISA.

In particular, the indicator of ICT availability at school (ICTSCH) measured the availability of various ICT devices

Table 10

Significance Testing of Mediators of Impact of ESCS on Scientific Literacy Performance

Mediator	Indirect effect ab	*SE* (Sobel) S_{ab}	PRODCLIN (95% asymmetric confidence interval based on the distribution of *ab*)
ICTSCH	0.012	0.004	[0.004, 0.021]
INTICT	0.046	0.004	[0.038, 0.055]
COMPICT	0.015	0.004	[0.007, 0.023]
AUTICT	0.047	0.004	[0.038, 0.057]

Note. When the PRODCLIN 95% asymmetric confidence interval does not cover 0, the strength of the mediating effect ab is statistically significant ($p < .05$).

Table 11

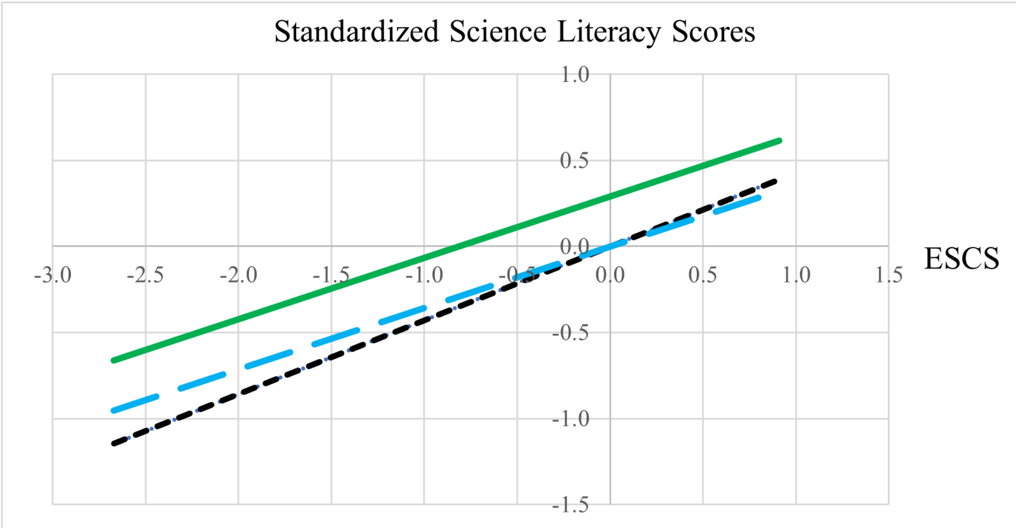
Finalized Multiple Regression Model Examining ICT Familiarity Related Mediators

Variable	Unstandardized		Standardized	
	B	SE_B	β	SE_β
Baseline model				
Impact of ESCS on scientific literacy	40.314*	2.512	0.429*	0.028
Full model				
Impact of ESCS	32.715*	2.461	0.357*	0.028
ICTSCH	1.464*	0.597	0.043*	0.018
INTICT	16.069*	1.737	0.138*	0.014
AUTICT on scientific literacy	12.074*	1.647	0.108*	0.014

Note. The above equations 1-3 controlled for the influence of student gender. *$p < .05$.

Figure 2

PISA 2015 ESCS Gradient Lines for Four Provinces and Cities in China



Note. (1) ESCS gradient line with standardized regression coefficients, without mediation effects (short, dashed line): PVSCIE = 0.429*ESCS; (2) ESCS gradient line with standardized regression coefficients, with mediation effects (long dashed line and solid line): PVSCIE = 0.357*ESCS + 0.043*ICTSCH + 0.138* INTICT + 0.108*AUTICT; (3) The solid line is the gradient line when the mediators are all set to 1; (4) The long, dashed line is the gradient line when the mediators are all set to 0; (5) The 5th and 95th percentiles of student ESCS values are −2.67 and 0.91, respectively, for the four provinces and cities in China.

in schools and whether students used these devices (see Table A2 in the Appendix). In fact, the scientific literacy performance of ESCS-advantaged students is better than that of ESCS-disadvantaged students. Some of the reasons may be that ESCS-advantaged students are admitted to schools with better ICT resources, and they also have more opportunities to access and use ICT for learning.

Under the broad concept of ICT engagement, student interest in ICT (INTICT) and student perceived autonomy around ICT use (AUTICT) were two mediators; their indirect effects were significantly greater than that of the ICT availability at school (ICTSCH) indicator (see Table 10). Another indicator, student perceived ICT competency (COMPICT), was found to have a mediating effect but was not included in the final model due to multicollinearity. According to the Theory of Self-determination, students with greater interest in ICT, greater autonomy around using ICT, and greater perceived ICT competencies have greater intrinsic motivation for ICT- and learning-related tasks. Such intrinsic motivation, when combined with proper meta-cognitive strategies, will help these students adjust their learning and problem-solving processes in a self-directed and effective manner, and will lead to high-quality learning, acquired conceptual understanding, and creativity, all of which are beneficial for self-development and adaptation. Students with high intrinsic motivation are also more likely to persevere in challenging yet interesting learning situations (Ieong, 2015).

In sum, the study demonstrates that ICT familiarity indicators can explain differences in scientific literacy performance among students of different ESCS. Therefore, addressing these indicators can be a useful starting point for reducing educational inequities in the four provinces and cities in China. Based on results of the study, the following recommendations are provided:

(1) Provide support for the construction of ICT facilities in schools and encourage a balanced distribution of ICT resources among schools, such that students may have roughly equal access to ICT regardless of which school they attend.

(2) After ICT facilities are widely accessible in schools across all regions and levels, ICT should be gradually integrated into the school curriculum to provide students with ample opportunities to interact with and

learn to use various ICT facilities/devices.

(3) Create a positive and supportive environment for ICT and establish a forward-looking learning culture in schools, thereby promoting the integration of ICT into instructions and increasing students' ICT engagement.

(4) When conditions permit, schools can host various forms of ICT-related extracurricular activities, such as within- and between-school ICT-related knowledge and skills contests, to foster ICT-related interest, competencies, and a sense of autonomy.

(5) Teachers should make full use of ICT resources in schools to aid instructions and mindfully design ICT-related courses and instructional activities. In particular, teachers should encourage and facilitate the use of ICT for learning among ESCS-disadvantaged students. Teachers should also instruct students to properly leverage ICT resources on campuses, and on a case-by-case basis, discourage students from engaging in ICT activities that are not related to learning.

(6) Emphases should be placed on assisting ESCS-disadvantaged students in using ICT and strengthening communication with parents, allowing both parents and schools to guide and monitor how ESCS-disadvantaged students use ICT.

(7) Create a classroom climate in support of student autonomy during instruction, mindfully foster ESCS-disadvantaged students' interest in using ICT, help students gain good experiences with using ICT for learning, and gradually cultivate good habits of using ICT for academic and personal development according to students' own needs.

(8) This study references how PISA examines educational equity and explores variables that mediate the impact on ESCS on student scientific literacy. However, the study does not consider the impact of ICT-related variables on other types of literacy nor the non-linear effects of such variables on literacy performance. Thus, it is recommended that future research explores these topics in depth.

References

Arpaci, S., Mercan, F. Ç., & Arikan, S. (2021). The differential relationships between PISA 2015 science performance and, ICT availability, ICT use and attitudes toward ICT across regions: Evidence from 35 countries. *Education and Information Technologies*, *26*, 6299–6318.

Baron, R. M., & Kenny, D. A. (1986). The moderator mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182.

Chen, C., & Gu, X. (2017). Examinig whether the internet exacerbates educational inequities — an empirical study based on PISA Shanghai data [in Chinese]. *Peking University Education Review*, *15*(1), 140–153.

Chen, J. (2015). *Fairness in basic education in Macao: An analysis of PISA 2006 data* [in Chinese]. Chengchi University Press.

Chiao, C., & Chiu, C. H. (2018). The mediating effect of ICT usage on the relationship between students' socioeconomic status and achievement. *The Asia-Pacific Education Researcher*, *27*(2), 109–121.

Deci, E. L., Vallerand, R. J., G., P. L., & Ryan, R. M. (1991). Motivation and education: The self-determination perspective. *Educational Psychologist*, *26*(3&4), 325–346.

Ieong, M. K. (2015). In search of resilience in learning variables mediating the effects of ESCS on mathematical literacy performance of adolescents in Macao: Through the lens of PISA 2012 [Unpublished doctoral dissertation]. University of Macau.

Kunina-Habenicht, O., & Goldhammer, F. (2020). ICT engagement: A new construct and its assessment in PISA 2015. *Large-scale Assessment in Education*, *8*, 1–21.

MacKinnon, D. P., & Fritz, M. S. (2007). Distribution of the product confidence limits for the indirect effect: Program PRODCLIN2. *Behavior Research Methods*, *39*(3), 384–389.

Mak, S. K. (2013). Explanation of gender differences in reading literacy for 15-year-old students in Macao: Mediating effects of reading engagement [in Chinese] [Unpublished doctoral dissertation]. University of Macau.

Michael, G. H., & Richard, L. (2019). The relationship of grade 7 students' general ICT use and attitudes towards ICT use for school related activities with ICT self-efficacy in eleven English program schools of Thailand. *Scholar: Human Sciences*, *11*(2), 366–384.

Ministry of Education of the People's Republic of China. (2016). *Notice by the Ministry of Education on disseminating the "13th Five-Year Plan for Educational Informatization"* [in Chinese]. Ministry of Education of the People's Republic of China. http://www.moe.gov.cn/srcsite/A16/s3342/201606/t20160622_269367.html

Odell, B., Cutumisu, M., & Gierl, M. (2020). A scoping review of the relationship between students' ICT and performance in mathematics and science in the PISA data. *Social Psychology of Education*, *23*, 1449–1481.

Organization for Economic Cooperation and Development. (2001). *Understanding the digital divide*. OECD Publishing.

Organization for Economic Cooperation and Development. (2009). *PISA data analysis manual: SPSS (2nd ed.)* OECD Publishing.

Organization for Economic Cooperation and Development. (2016). *PISA 2015 results (volume I): Excellent and equity in education*. OECD Publishing.

Organization for Economic Cooperation and Development. (2017a). *PISA 2015 assessment and analytical framework: Science, reading, mathematic, financial literacy and collaborative problem solving (revised edition)*. OECD Publishing.

Organization for Economic Cooperation and Development. (2017b). *PISA 2015 technical report*. OECD Publishing.

Organization for Economic Cooperation and Development. (2017c). *Revised edition of PISA 2015 assessment and analytical framework: Science, reading, mathematic, financial literacy and collaborative problem solving*. OECD Publishing.

Organization for Economic Cooperation and Development. (2018). *Equity in education: Breaking down barriers to social mobility*. OECD Publishing.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*, 54–67.

Sobel, M. E. (1982). Asymptotic confidence intervals for indirect effects in structural equation models. *Sociological Methodology*, *13*, 290–312.

Xiao, Y., & Hu, J. (2019). The moderation examination of ICT use on the association between Chinese mainland students' socioeconomic status and reading achievement. *International Journal of Emerging Technologies in Learning*, *14*(15), 107–120.

Zhu, J., & Li, S. C. (2022). The non-linear relationships between ICT use and academic achievement of secondary students in Hong Kong. *Computers & Education*, *187*, 104546.

Zylka, J., Christoph, G., Kroehne, U., Hartig, J., & Goldhammer, F. (2015). Moving beyond cognitive elements of ICT literacy: First evidence on the structure of ICT engagement. *Computers in Human Behavior*, *12*(53), 149–160.

Appendix: PISA 2015 ICT Familiarity Variables – International English Version Questionnaire Items

Table A1: ICT Availability at Home (ICTHOME) Indicator Questionnaire Items

Are any of these devices available for you to use at home?
(1: Yes, and I use it 2: Yes, but I don't use it 3: No)

- Desktop computer
- Portable laptop, or notebook
- <Tablet computer> (e.g., <iPad®>, <BlackBerry® PlayBook>)
- Internet connection
- <Video games console>, e.g., <Sony® PlayStation®>
- <Cell phone> (without Internet access)
- <Cell phone> (with Internet access)
- Portable music player (Mp3\Mp4 player, iPod® or similar)
- Printer
- USB (memory) stick
- <eBook reader>, e.g., <Amazon® Kindle>

Note. Each participating country/economy may adjust the content in brackets according to the actual situation.
Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A2: ICT Availability at School (ICTSCH) Indicator Questionnaire Items

Are any of these devices available for you to use at school?
(1: Yes, and I use it 2: Yes, but I don't use it 3: No)

- Desktop computer
- Portable laptop or notebook
- <Tablet computer> (e.g., <iPad®>, <BlackBerry® PlayBook>)
- Internet connected school computers
- Internet connection via wireless network
- Storage space for school-related data, e.g., a folder for own documents
- USB (memory) stick
- <eBook reader>, e.g., <Amazon® Kindle>
- Data projector, e.g., for slide presentations
- Interactive Whiteboard, e.g., <Smartboard®>

Note. Each participating country/economy may adjust the content in brackets according to the actual situation.
Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A3: ICT Use for Entertainment Outside School (ENTUSE) Indicator Questionnaire Items

How often do you use digital devices for the following activities outside of school?
(1: Never or hardly ever 2: Once or twice a month 3: Once or twice a week
4: Almost every day 5: Every day)

- playing one-player games
- playing collaborative online games
- using email
- <Chatting online> (e.g., <MSN®>)
- social networks (e.g., <Facebook>, <MySpace>)
- online games or Social Networks (e.g., <Farmville®>, <The Sims Social>)
- browsing the Internet for fun videos, e.g., <YouTube>)
- reading news on the Internet (e.g., current affairs)
- obtaining practical information from the Internet
- downloading music, films, games or software from the Internet
- uploading your own created contents for sharing
- downloading new apps on a mobile device

Note. Each participating country/economy may adjust the content in brackets according to the actual situation.
Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A4: Schoolwork-Related ICT Use at Home (HOMESCH) Indicator Questionnaire Items

How often do you use digital devices for the following activities outside of school?
(1: Never or hardly ever 2: Once or twice a month 3: Once or twice a week
4: Almost every day 5: Every day)

- Browsing the Internet for schoolwork (e.g., for preparing an essay or presentation)
- Browsing the Internet to follow up lessons, e.g., for finding explanations
- Using email for communication with other students about schoolwork
- Using email for communication with teacher and submission of homework or other schoolwork
- Using Social Networks for communication with other students about schoolwork (e.g. , <Facebook>, <Myspace>)
- Using Social Networks for communication with teachers (e.g. , <Facebook>, <Myspace>)
- Downloading, uploading or browsing from school website (e.g., timetable or course materials)
- Checking the school's website for announcements, e.g., absence of teachers
- Doing homework on a computer
- Doing homework on a mobile device
- Downloading learning apps on a mobile device
- Downloading science learning apps on a mobile device

Note. Each participating country/economy may adjust the content in brackets according to the actual situation.
Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A5: ICT Use at School (USESCH) Indicator Questionnaire Items

How often do you use digital devices for the following activities at school?
(1: Never or hardly ever 2: Once or twice a month 3: Once or twice a week 4: Almost every day 5: Every day)

- <Chatting online> at school
- Using email at school
- Browsing the Internet for schoolwork
- Downloading, uploading or browsing materials from the school's website (e.g., <intranet>)
- Posting my work on the school's website
- Playing simulations at school
- Practicing and drilling, such as for foreign language learning or mathematics
- Doing homework on a school computer
- Using school computers for group work and communication with other students

Note. Each participating country/economy may adjust the content in brackets according to the actual situation.
Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A6: Student Interest in ICT (INTICT) Indicator Questionnaire Items

Thinking about your experience with digital media and digital devices: to what extent do you disagree or agree with the following statements?
(1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree)

- I forget about time when I'm using digital devices
- The Internet is a great resource for obtaining information I am interested in (e.g., news, sports, dictionary)
- It is very useful to have Social Networks on the Internet
- I am really excited discovering new digital devices or applications
- I really feel bad if no Internet connection is possible
- I like using digital devices

Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A7: Student Perceived ICT Competency (COMPICT) Indicator Questionnaire Items

Thinking about your experience with digital media and digital devices: to what extent do you disagree or agree with the following statements?
(1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree)

- I feel comfortable using digital devices that I am less familiar with
- If my friends and relatives want to buy new digital devices or applications, I can give them advice
- I feel comfortable using my digital devices at home
- When I come across problems with digital devices, I think I can solve them
- If my friends and relatives have a problem with digital devices, I can help them

Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A8: Student Perceived Autonomy Around ICT Use (AUTICT) Indicator Questionnaire Items

Thinking about your experience with digital media and digital devices: to what extent do you disagree or agree with the following statements? (1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree)
• If I need new software, I install it by myself
• I read information about digital devices to be independent
• I use digital devices as I want to use them
• If I have a problem with digital devices, I start to solve it on my own
• If I need a new application, I choose it by myself

Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf

Table A9: Inclusion of ICT as a Topic in Social Interactions (SOIAICT) Indicator Questionnaire Items

Thinking about your experience with digital media and digital devices: to what extent do you disagree or agree with the following statements? (1: Strongly disagree 2: Disagree 3: Agree 4: Strongly agree)
• To learn something new about digital devices, I like to talk about them with my friends.
• I like to exchange solutions to problems with digital devices with others on the Internet.
• I like to meet friends and play computer and video games with them.
• I like to share information about digital devices with my friends.
• I learn a lot about digital media by discussing with my friends and relatives.

Sourced from https://www.oecd.org/pisa/data/CY6_QST_MS_ICQ_Final.pdf