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Linear or quadratic effects of ICT use on science and mathematics achievements moderated by SES: conditioned ecological techno-process

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ABSTRACT

Aim and background: This study investigated the effects of information and communication technology (ICT) use patterns, moderated by socioeconomic status (SES), on science and mathematics achievements. This investigation aims to address the issue of whether ICT use has 'conditioned' (linear and quadratic) effects on achievements with SES as social conditions, based on a posited Conditioned Ecological Techno-process (CET) model.

Method: Data from the 2012 Program for International Student Assessment for Taiwan were analyzed using regression analysis focusing on the effect of three ICT use patterns (leisure, educational, and school).

Results: The results support the CET model in the quadratic effects of all the three ICT use patterns on both achievements in addition to the positive linear effects of educational ICT use and the negative linear effects of leisure and school ICT use patterns. The moderation effect of SES only occurs with leisure ICT use on science achievement.

Discussion: The findings suggest that moderate frequent ICT use predicts the highest achievements. SES may aggravate the negative effect of leisure ICT use on science achievement.

KEYWORDS
Ecological technology theory; information and communication technology; PISA; science and mathematics achievement; socioeconomic status

Governments, families, and schools have committed to invest in information and communication technology (ICT). The investment can prepare their nationals, next generations, and students for the modern digital society (Lim et al. 2013). ICT use is especially crucial for science and mathematics education, where a demanding workforce for the fourth industrial revolution featuring autonomous robotics and artificial intelligence is needed (Colvin 2015).

However, the cost-effectiveness of ICT still needs to be evaluated in terms of its impacts on students' learning outcomes as traditionally indicated in curricular standards such as achievement in science and mathematics (Chiu and Whitebread 2011; Rodríguez, Nussbaum, and Dombrovskaia 2012). In other words, science and mathematics achievements can serve as readily available criteria for evaluating the effectiveness of students' ICT use in both inside and outside school settings especially given the rapid development of mobile technology in recent years.

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This study, therefore, focuses on evaluating the effectiveness of different ICT use patterns by linking them to science and mathematics achievement, as advocated by literature, national curricula, and diverse cultures. To address this study focus, related literature is widely searched to identify improvable knowledge as the problem context, followed by using a theoretical basis aiming to advance the improvable knowledge and suggest examined measures and their relationships for proposing research questions.

The problem context and theory basis

The problem context: linear or quadratic effects of ICT use on achievement?

Previous studies have reported that the effects of ICT use on ICT skills tend to be positive (Claro et al. 2012), which implies a simple linear relationship between ICT use and learning outcomes. A simple linear relationship means that more ICT use relates to higher achievements and vice versa. However, past research shows that the effects of ICT use on achievement are inconsistent (Hinvest and Brosnan 2012) and excessive use of ICT may have an undesirable impact on achievement (Gubbels, Swart, and Groen 2020). Qualitative and historical research reveals that ICT-infused pedagogies related to positive learning outcomes are those moderately using ICT to address real-world teaching issues (Ross, Morrison, and Lowther 2010). These effective teachers give lectures, reorganise curricula, and monitor students' higher-order abilities (e.g. collaborative research, problem-solving, and information management) (Kozma 2003). The educational effectiveness of ICT investments has therefore been called into question (Hammond 2014) and requires further investigation.

Although not clearly indicated, the results of Lei and Zhao (2007) study presents a quadratic relationship between ICT use frequency and achievements. The quadratic relationship, as will be discussed in greater detail in the literature review, suggests that moderate ICT use may optimize achievements. This forms a reverse U-shaped relationship between student achievement and ICT use frequency (e.g. Figure 2). This inverted U-shaped pattern reveals a sign of a personal condition, including self-regulation (Zimmerman 1990) or social regulation (Grau and Whitebread 2012). While striving to optimize or maximize self-development, human beings remain a harmonic interaction between their outside world (e.g. fast-changing ICT development and related designs) and inside world (e.g. existing mindset and well-being).

The first major purpose of this study, therefore, is to investigate these quadratic relationships between students' learning outcomes and ICT use frequencies in education, which have been heretofore overlooked in the literature. Extending from linear to quadratic relationships, however, needs a theoretical background to guide the proposition of hypotheses.

Theoretical basis: ecological theories of educational technology

The ecological theories of educational technology indicate that educational technology will assist students to generate multi-dimensional learning outcomes such as cognitive, emotional and social ones, as suggested by the 'Ecological Techno-Microsystem' (Johnson 2010). The 'Ecological Techno-Subsystem' (Johnson and Puplampu 2008) insists that positive effects of educational technology on learning outcomes need support from ecological factors such as people (e.g. parents and peers), technological devices (e.g.

computer and software) in the microsystem, indirect environment (e.g. organizations and governments) in the exosystem, and cultures (e.g. values and beliefs) in the macrosystem. Intensive networking and connection between several factors in the microsystem form the mesosystem or proximal process. The mesosystem or proximal process has proved itself to create increased positive effects of educational technology on learning outcomes. Example studies include connecting school homework with parental collaboration in the 'Activities with Parents on the Computer' networking frame (Paiva, Morais, and Moreira 2017) and links from inside- to out-school ICT use with socioeconomic status (SES) as a mediator in the 'Ecological Techno-Process (Chiu 2019).'

The inconsistent effects of ICT use may also be engendered by distinct meanings and complex relationships between ICT use patterns and learning outcomes, conditioned by ICT use backgrounds (e.g. SES; Voogt et al. 2013). Qualitative research has indicated that ICT use patterns (e.g. leisure or educational ICT use) rather than ICT use availability tend to play a major role in benefiting the learning outcomes of children from disadvantaged families (Angus, Snyder, and Sutherland-Smith 2004). These studies highlight the importance of diverse ICT use patterns, which may be socially conditioned by students' SES and personal processes.

In summary, ecological theories of educational technology explain how multilevel systems of ICT use impact achievement. The mesosystem sheds new light on personal processes and social conditions. This study, therefore, aims to examine how students' achievements are related to their process and background of diverse ICT use patterns. To address the aim, this study posits a 'Conditioned Ecological Techno-process (CET)' model (Figure 1). The CET model highlights 'the linear and quadratic effects' of diverse ICT use patterns (in the microsystem) as a 'personally conditioned' proximal process and the

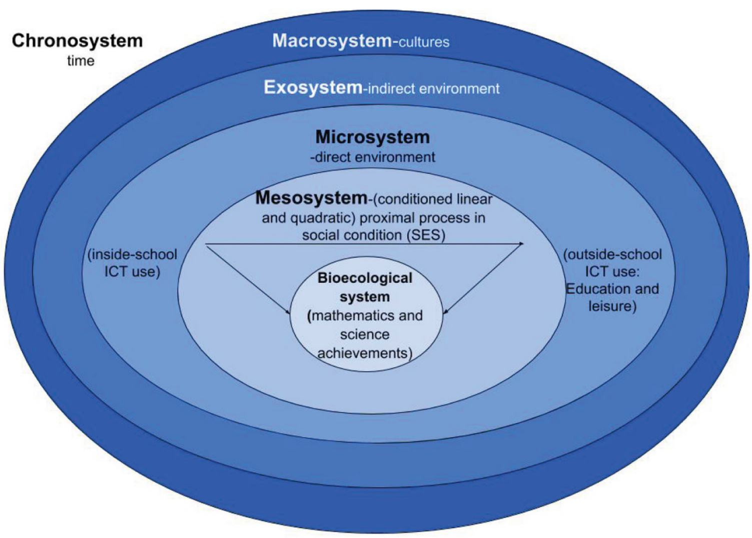

Figure 1. A Conditioned Ecological Techno-process (CET) model, focusing on the linear and quadratic effects of diverse ICT use patterns (in the microsystem) as the proximal process and the family SES as the condition in the mesosystem on science and mathematics achievements in the bioecological system. The content inside in Figure 1 is examined in this study.

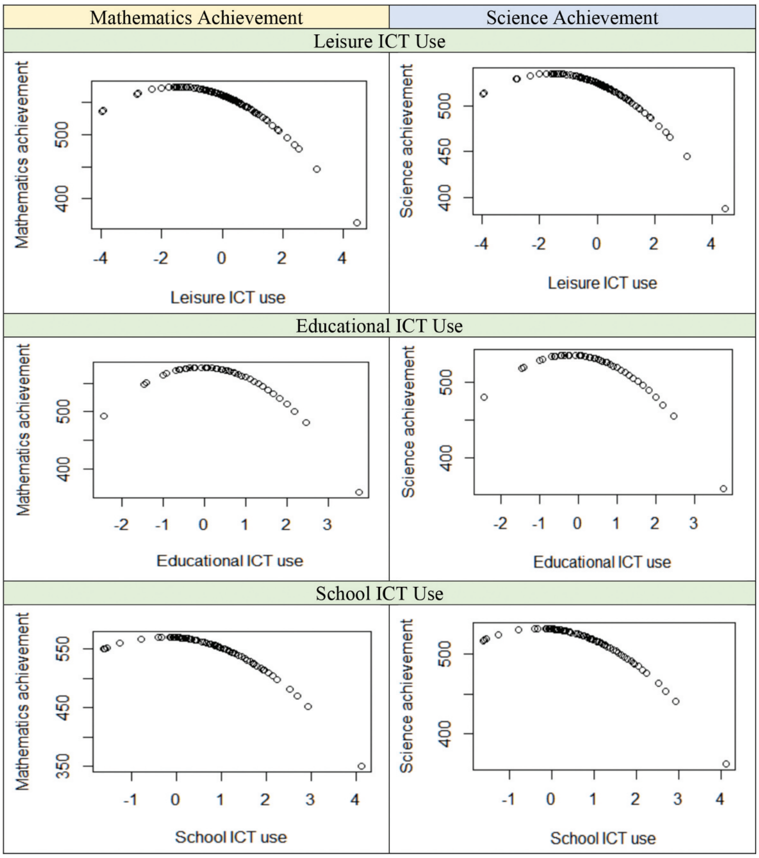

Figure 2. Relationships of the three ICT use patterns with science and mathematics achievements.

family SES as the social condition (in the mesosystem). Both the personal conditioned process and social condition impact science and mathematics achievements in the bioecological system. The CET serves as a revision of the 'Ecological Techno-Process' framework (Chiu 2019).

Focused measures and relationships in the CET model

ICT use patterns: leisure, educational, and school ICT Use

Researchers have generally categorized student ICT use patterns based on either purpose, such as for leisure (playful) and educational (academic) uses (Tømte and Hatlevik 2011) or places, such as school and home uses (Kent and Facer 2004). Later research has directly divided ICT use into three categories: leisure (playful), educational (schoolwork), and school (classroom) ICT use (Tondeur et al. 2010).

ICT use purposes and places are not orthogonal concepts. Even though certain activities may be promoted in a given context, students engage in both playful and educational activities at school and at home (Selwyn, Potter, and Cranmer 2009). School ICT use emphasizes educational purposes such as researching, learning, and promoting ICT skills and is supervised by teachers (Samuelsson 2010). Home ICT use tends to focus more on leisure purposes such as playing games (Mumtaz 2001) and less on educational purposes such as doing homework and using educational software (Malamud and Pop-Eleches 2011). Moreover, the use of online social networks appears to diminish the boundaries between students' social lives inside and outside of school (Junco 2012), with outside school social networks serving as an extension of inside school ones (Kent and Facer 2004).

The Program for International Student Assessment (PISA) conducted in 2012 (OECD, 2014) focused on three ICT use patterns: home leisure, home educational, and school ICT use. Although this classification system is not thorough (e.g. to add school ICT use for leisure and education purposes), it is reasonable to assume that educators manage school ICT use under the regulations of the education system. For example, playing ICT games at school is normally part of teaching activities. This study used PISA data and thus followed this classification system (cf. Method/Data Source and Sample; Measures).

Relationships between achievements and ICT Use patterns

Linear relationships. Most studies on the relationships between achievements and ICT use patterns have focused on their linear relationships. Leisure ICT use tends to negatively relate to achievements, which may be due to decreased study hours (Kirschner and Karpinski 2010), reduced metacognitive strategy use (Lee and Wu 2013), and excessive multitasking (Junco and Cotten 2012). Studies have found both positive (Lee and Wu 2013) and negative (Valentín et al. 2013) relationships between achievements and educational ICT use. Likewise, the relationship between achievements and school ICT use may be positive or negative (Tamim et al. 2011). Simply introducing ICT into schools without promoting desirable teaching may not benefit students in the realm of achievements, even when SES, ICT use patterns and availability, and prior academic abilities are controlled for (Ravizza, Hambrick, and Fenn 2014).

Quadratic relationships. Previous studies appear to merely indirectly address quadratic relationships between achievements and ICT use. Lei and Zhao (2007, 288) demonstrated that secondary students using ICT for 4 hours per day had the lowest achievement; 3 hours, the highest achievement; and 1 hour, the middle achievement. The reverse U-shaped relationship between student achievements and time spent using the computer in Lei and Zhao's findings suggested a quadratic relationship between ICT use and achievements, but the authors did not explicitly state this in their study.

Some innovative pedagogies emphasizing mixing both traditional face-to-face and modern ICT-infused pedagogies such as blended learning (Porter et al. 2014) and flipped classroom (Flumerfelt and Green 2013) have proven successful. There appear to be no salient theories addressing the quadratic effects between achievements and ICT use. Existing theories that emphasize diverse, multiple, and complex learning and teaching modes benefiting higher-order learning outcomes may serve as an initial theoretical basis for the quadratic effects of ICT use on learning outcomes in this study. Examples of these existing theories include self-regulation (Lipsey et al. 2017), deep learning approaches (Baeten et al. 2010), and multiple intelligences or multimodal pedagogies (Perveen 2018). This study directly examines these quadratic effects of ICT use on learning outcomes and provides empirical evidence and an initial theoretical foundation for existing and future innovations in ICT-infused pedagogies.

Roles of SES in relationships between learning outcomes and ICT use

As suggested by the CET model, SES is a social condition in the mesosystem that moderates the effects of diverse ICT use patterns on achievement. In other words, SES interacts with ICT use and then plays a role in achievement.

SES normally positively relates to computer availability (especially at home), ICT use, and achievements (Lee and Wu 2012). Several studies, however, have reported contradictory results. SES does not, for example, relate to home computer availability and negatively relates to ICT attitudes for secondary students in a study conducted in Flanders, Belgium (Tondeur et al. 2010). National and community differences may partly explain the mechanisms underlying the involvement of SES in the relationships between learning outcomes and ICT use. As such, this study will control for the direct effects of SES and ICT availability at home and at school in order to preclude these confounding factors. With these confounding effects controlled for in the regression analyses, this study can focus on the moderating role of SES.

First, SES may contribute to the linear effect of ICT use on learning outcomes. Kubiatko and Vlckova (2010) determined that students who occasionally used ICT at home or who had prolonged ICT use experience (in years) registered higher science achievements compared with those who never used ICT or who had experienced it for only one year. However, they fail to consider the possibility that SES may intervene in the relationships between ICT use (particularly at home) and learning outcomes. For example, SES may be one common factor for both achievements and ICT availability, ICT use frequency or ICT use patterns. It may be misleading to stress a simple relationship between ICT use and achievement without considering SES.

Second, SES may contribute to the quadratic effect of ICT use on learning outcomes in addition to the linear effect. This is because SES may address the gap in ICT educational resources in terms of both economics (e.g. ICT equipment) and social/educational aspects (e.g. parents and teachers monitoring their students' interaction with ICT). Thus, SES will likely change the marginal learning outcomes from ICT use when students increase their ICT use frequency. If this is the case, then additional educational investment in ICT for low-SES students, schools or families may decrease the gap in learning outcomes between low and high SES students. ICT equipment investment for high-SES students may have a low impact due to a ceiling effect in the economic aspect. However, high-SES students still need support for educational ICT use because their affluent parents may lack such knowledge and skills.

Third, SES may moderate different patterns of ICT use on learning outcomes. In theory, ICT is a tool that provides opportunities for students with low SES to increase their academic achievement (Yang et al. 2013). Nevertheless, studies have indicated that simple increases in ICT availability may fail to increase student achievements and attendance. SES consistently relates to educational and advanced ICT use, such as writing, developing e-materials (Vekiri 2010), using search engines, and sharing ideas online, but negatively to playing games (Nasah et al. 2010).

Specifically, SES may interact with various ICT use patterns and in turn play different roles in student learning outcomes, particularly in a country where ICT use has become a low-cost behavior (e.g. Taiwan). For example, if high SES students frequently play computer games only for entertainment purposes, then high SES students' achievement may decrease more than low SES students. In contrast, if high SES students focus on ICT use for educational purposes, then high SES students may benefit from ICT use more than low SES students do. The prediction is based on the rationale that parents of high SES children may provide more cognitive scaffolding that involves adaptive teaching and prompts to promote their children' cognitive development when their children interact with ICT than parents of low SES students do (Vogel et al. 2017).

As has been addressed, except for leisure ICT use, educational and school ICT use patterns have unstable relationships with achievement (Lee and Wu 2013; Ravizza, Hambrick, and Fenn 2014; Tamim et al. 2011; Valentín et al. 2013). This allows little opportunity to find a significant moderation effect of any variable on achievement although the relationship between SES and achievement is stable. Therefore, the moderation effect of SES on achievement is tentative. Given all these concerns, even with theoretical support of the CET model, it appears to be more suitable to propose a research question (RQ) rather than a hypothesis for the present investigation.

Research question

The literature review above suggests that the relationships between ICT use and achievements follow an inverted U relationship (e.g. Figure 2). This relationship is explainable by a posited CET model (Figure 1). The CET model assumes that ICT can be used in three patterns (outside-school leisure and educational ICT uses as well as school ICT use) in the microsystem, which impacts science and mathematics achievement in the bioecological system. This impact occurs under the mesosystem of the conditioned linear and quadratic proximal process in social conditions (e.g. SES). While SES in the economic aspect (e.g. ICT availability at home and school) can determine the effect of ICT use, SES in the social aspect may interact with ICT use patterns to play a moderating role in achievement.

This study thus attempted to answer the RQ: Are science and mathematics achievements, respectively, predicted by the linear and quadratic effects of diverse ICT use patterns and the moderation effects of SES, controlling for the linear effects of SES and ICT availability at home and school?

Figure A1 in the Appendix provides a diagrammatical model to represent the RQ in terms of statistical operation. The data entry process and analysis procedure to address the RQ are presented in the Data Analysis section.

Method

Data source and sample

Data were collected from the main and ICT surveys of the PISA 2012 study (OECD 2014). PISA is a triennial survey that has been conducted by OECD and other countries or economies since 2000. It assesses the achievements of 15-year-old students in mathematics, reading, and science in addition to collecting related student, parent, and school background information. PISA 2012 was the fifth survey focusing on mathematics, with a minor focus on reading, science, and problem-solving. In PISA 2012, the ICT survey was optional and focused on ICT availability, uses, and attitudes. The variables of 'CNT (country code)' and 'IC01Q01 (the first item in the ICT questionnaire)' in the PISA 2012 student data set contained 485,490 students from 68 countries or economies, and the ICT survey involved 296,977 students from 43 countries.

This study used the PISA 2012 Taiwan data. Taiwan participated in both the main and ICT surveys of the PISA 2012, in which a total of 6,046 students from 163 schools participated.

Measures

This study applied eight student measures from the PISA 2012 database (OECD 2014). These measures were grouped into three categories: achievements, ICT use patterns, and ICT use backgrounds. Table 1 provides the measure names used in this study; PISA labels and names; item stems, samples, and numbers; measurement methods; and reliabilities for OECD countries and Taiwan.

The achievement category comprised two measures that were obtained on the basis of student cognitive ability tests and scaled using item response theory (IRT) with the metric of the mean (*M*) = 500 and standard deviation (*SD*) = 100. Higher scores represented higher achievements (OECD 2014, 159).

The categories of ICT use patterns and ICT use backgrounds comprised six measures (each category with three measures). The items were obtained from the student questionnaire survey. As shown in Table 1, the six measures have different measurement methods: The items for the three ICT use patterns were rated on a 5-point Likert scale ranging from 1 = *never or hardly ever* to 5 = *every day*. SES was computed using three z-scores from items on home possession, parental occupation, and parental education. Items for ICT availability were rated on a 3-point Likert scale from 1 = *yes, and I use it* to 3 = *no* (reverse coded). Finally, the six measures separately were internationally scaled using IRT with OECD $M = 0$ and $SD = 1$. Higher scores represented higher degrees in the meanings of the measure names (OECD 2014, 312).

Statistical analysis

The research question was answered by conducting statistical analysis using R Version 3.4.3 (R Core Team, http://www.R-project.org/). Descriptive statistics and correlation analyses were performed in order to provide an initial picture of the eight measures (Table 2). Descriptive statistics were obtained using the R psych package. Pearson's bivariate correlation analysis was performed using the R stats package. Missing data were addressed using pairwise deletion. Correlations are grouped into three levels: the correlation coefficients (in absolute values) lower than or equal to.35 are considered weak, those from .36 to .67 are considered moderate, and those from .68 to 1.00 are considered strong (Taylor 1990).

Science and mathematics achievements were highly correlated ($r = 0.93$; Table 2). The six predictors (i.e. Measures 3–8 in Tables 1–2) had generally low correlation coefficients (rs = 0.004 to 0.29) except for the moderate correlations between educational and school ICT uses ($r = 0.39$) and between SES and home ICT availability ($r = 0.44$). Correlations of SES with science and mathematics achievements were moderate (rs = 0.42 and 0.40).

Table 1. Detailed Descriptions of the Examined Measures.

Measure name (abbreviation)	PISA label/name	Item stems and sample items (item numbers)	Measurement methods	OECD α	Taiwan α
Cognitive outcomes					
1.Mathematics achievement	Plausible value 1 in mathematics/pv1math	(PISA 2012 Released Items)	Cognitive test	.91	.94
2.Science achievement	Plausible value 1 in science/pv1scie	(PISA 2012 Released Items)	Cognitive test	.89	.91
ICT use patterns					
3. Leisure ICT use	ICT entertainment use/entuse	How often do you use a computer for the following activities outside of school? Playing one-player games; participating in social networks. (10 items)	5-point Likert scale: 1 = never or hardly ever ~ 5 = every day	.78	.83
4. Educational ICT use	ICT Use at home for school-related tasks/homsch	How often do you use a computer for the following activities outside of school? Browsing the Internet for schoolwork; doing homework on the computer. (7 items)	(Same as the above)	.83	.86
5. School ICT use	Use of ICT at school/usesch	How often do you use a computer for the following activities at school? Using email; playing simulations. (9 items)	(Same as the above)	.85	.85
ICT use backgrounds					
6. SES	Index of economic, social and cultural status/escs	(Original item stems can be found in the student questionnaire.) Home possessions; the highest parental occupation; the highest parental education. (3 items)	3 derived items, each z-standardized	.65	.69
7. Home ICT availability	ICT availability at home/icthome	Are any of these devices available for you to use at home? Desktop computer; internet connection. (11 items)	3-point Likert scale: 1 = yes, and I use it, 2 = yes, but I don't use it, 3 = no (reverse coded)	.53	.63
8. School ICT availability	ICT availability at school/ictsch	Are any of these devices available for you to use at school? Desktop computer; internet connection. (7 items)	(Same as the above)	.65	.59

The information of this table is obtained from OECD (2014) except for measure names. α = Cronbach's alpha (internal reliability coefficient).

Table 2. Descriptive Statistics and Correlations between the Examined Measures.

	N	Mean	SD	1	2	3	4	5	6	7
1 Mathematics achievement	6046	557.58	115.03							
2 Science achievement	6046	522.06	83.32	0.93***						
3 Leisure ICT use	6000	−0.20	0.99	−0.13***	−0.13***					
4 Educational ICT use	5985	−0.51	1.01	0.16***	0.14***	0.27***				
5 School ICT use	5978	−0.24	0.97	−0.01	−0.01	0.20***	0.39***			
6 SES	6023	−0.39	0.85	0.42***	0.40***	0.004	0.16***	0.04**		
7 Home ICT availability	6013	−0.35	0.93	0.12***	0.09***	0.24***	0.15***	0.07***	0.44***	
8 School ICT availability	6000	−0.23	0.81	0.04**	0.03*	0.08***	0.20***	0.29***	0.09***	0.22***

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$. SD = standard deviation.

The results partially confirmed that SES addressed gaps in learning outcomes, ICT use patterns, and ICT availability, as suggested by previous studies (e.g. Kubiatko and Vlckova 2010). As such, the linear effects of SES and ICT availability at home and school were included in the regression model as a control; that is, their direct effects were ruled out. That allows the analyses to focus on the effects of SES in moderating the relationships between ICT use patterns and achievements.

Regression analysis enables using small sample sizes to examine simple predictive models and facilitates conducting comparisons between models. The sample size of this study was sufficient to generate reliable predictive coefficient estimates given the number of the predictors and the percentages of the total variances of the outcomes explained by the predictors in the models (Knofczynski and Mundfrom 2008).

Regression analysis was performed using the R stats package for examining the effects of predictors (ICT use patterns and backgrounds) on achievements, with the final student weight ('w_fstuwt' in PISA 2012) activated. The sum of these weights constituted an estimate of the size of the target population and thus activating the weights allowed the analysis results to represent the phenomenon of the population. The linear and quadratic effects were depicted using the car package (Fox and Weisberg 2011). The regression table was initially formed by the R stargazer package (Hlavac 2018).

The data entry process started with calculating derived measures (e.g. quadratic and moderation ones). Then, all the 15 predictors simultaneously predict the outcome (mathematics in Model 1 and science in Model 2 of Table 3) using multiple linear regression analysis because the literature was sufficient enough to propose the RQ. Multicollinearity was not a serious concern in the present regression analyses because of low correlations (lower than .90) between the predictors (Measures 3–8 in Table 2; Hair et al. 2006). All the measures were mean-centered standardized scores, which reduced the problem of multicollinearity in examining the moderating (or interaction) effects where two measures are multiplied (e.g. SES * leisure ICT use; Dawson 2014). The R code for this process is presented in the Appendix.

Results

Table 3 presents the results of two regression analyses (Models 1–2) for science and mathematics achievements, respectively. The two models were all statistically significant, as indicated by the significant *F* statistics.

The percentages that the predictors explained the total variance in the two learning outcomes were 25% for mathematics achievement and 24% for science achievement.

Table 3. Regression Analysis Results (Estimated Coefficients (β) and Standard Error) for the two Outcomes Regressed on Three ICT Use Patterns, Moderated by SES, Controlled by Backgrounds.

Predictor \ *Dependent variable*	Mathematics achievement	Science achievement
	Model 1	Model 2
Controls		
SES	0.41*** (0.02)	0.40*** (0.02)
Home ICT availability	−0.05*** (0.01)	−0.07*** (0.01)
School ICT availability	−0.01 (0.01)	−0.01 (0.01)
ICT use patterns		
Leisure ICT use (linear)	−0.16*** (0.01)	−0.14*** (0.01)
Leisure ICT use (quadratic)	−0.08*** (0.01)	−0.08*** (0.01)
Educational ICT use (linear)	0.04** (0.02)	0.03 (0.02)
Educational ICT use (quadratic)	−0.16*** (0.02)	−0.16*** (0.02)
School ICT use (linear)	−0.05*** (0.02)	−0.06*** (0.02)
School ICT use (quadratic)	−0.07*** (0.01)	−0.08*** (0.01)
SES moderation		
SES * Leisure ICT use (linear)	−0.02 (0.01)	−0.03* (0.01)
SES * Leisure ICT use (quadratic)	−0.004 (0.02)	−0.004 (0.02)
SES * Educational ICT use (linear)	0.01 (0.02)	0.03 (0.02)
SES * Educational ICT use (quadratic)	0.02 (0.02)	0.03 (0.02)
SES * School ICT use (linear)	0.02 (0.02)	0.02 (0.02)
SES * School ICT use (quadratic)	−0.01 (0.02)	−0.003 (0.02)
Adjusted R^2	0.25	0.24
F Statistic (degree of freedom)	131.70*** (15; 5928)	123.39*** (15; 5928)

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

One-fourth of the total variances of the outcomes explained are reasonable, though small. It is because this study only investigated six predictors (Measures 3–8 in Table 1), which are only part of the microsystem and mesosystem in the CET model.

Detailed results of how the predictors predict the two outcomes are described as follows.

Controls

Three predictors, SES and ICT availability at home and school, played the role of control in the regression analysis. SES had the strongest effects on science and mathematics achievements compared to all other predictors in the models (βs = 0.41 and 0.40; Table 3). Home ICT availability had weak but significant effects (βs = −0.05 and −0.07). School ICT availability had no significant effects on achievements (β = −0.01 for each achievement). This result implies that school ICT availability has little impact on achievements. Another reason may be the relatively low variation (standard deviation [SD] = 0.81) of ICT availability in Taiwan schools (Table 2; cf. OECD countries with SD = 1.00; cf. the Measure section).

When explaining regression analysis results, a regression coefficient demonstrates the effect of a particular predictor on an outcome controlling for all of the other predictors in the regression model. Home and school ICT use had changes in signs from correlation analysis (positive) to regression analysis (negative and non-significant). This means that home and school ICT availability became negative or non-significant in predicting achievements when controlling for the effects of ICT use patterns and SES in the regression analysis. This result concurred with the notion that ICT equipment is not the key but ICT use patterns are important in determining students' achievements (Ravizza, Hambrick, and Fenn 2014).

Linear or quadratic effects of ICT use patterns

Achievement and ICT use follow a reverse U-shaped relationship (Figure 2). As evidenced by regression analysis results, both leisure and school ICT use patterns not only negatively linearly (β = –0.05 to –0.16) but also negatively quadratically (βs = –0.07 to –0.08) predicted student achievements in science and mathematics (Models 1–2 in Table 3). Educational ICT use had positive linear effects (βs = 0.04 and 0.03) and negative quadratic effects (both βs = –0.16) on science and mathematics achievements although the linear effect on science achievement is non-significant (β = 0.03). This formed a much more typical reverse U-shaped function (Educational ICT Use in Figure 1). In summary, the quadratic effects of the three ICT use patterns on both science and mathematics achievements were consistently in a reverse U shape but their linear effects were different in directions and degrees of significance.

A comparison between the effects of the three ICT use patterns revealed that leisure ICT use had relatively strong, negative linear effects on achievement (βs = –0.16 and –0.14). Educational ICT use had relatively strong, negative quadratic effects (both βs = –0.16). The effects of school ICT use had patterns of effects similar to those of leisure ICT use (all negative) (βs = –0.05 to –0.08) but their effects were relatively weak, though significant.

SES moderation effects

Only one SES moderation effect occurred. The interactions between SES and leisure ICT use (linear) had a significant negative effect on science achievement (β = –.0.03; Model 2, Table 3).

The results revealed that SES moderated the effects of leisure ICT use on science achievement in a negative direction. As shown in Figure 3, the difference in science achievement between high- and low-SES students is 58.88 for low leisure ICT users but reduced to 43.97 for high leisure ICT users. The difference is 14.91(= 58.88–43.97) but

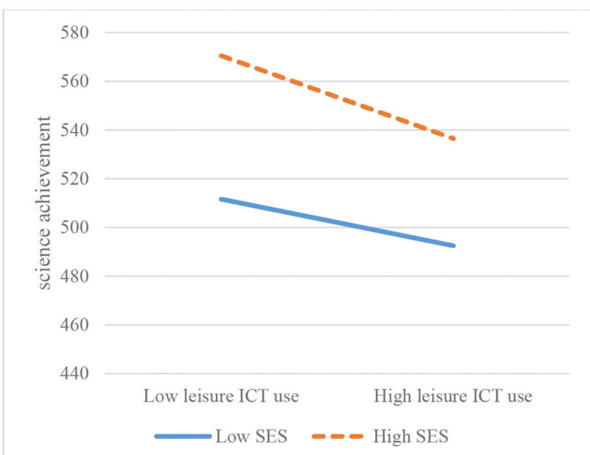

Figure 3. SES moderates the effects of leisure ICT use (linear) on science achievement.

small in terms of 0.18 standard deviation (SD) of science achievement (=14.91/83.32; Table 2). The results implied that high-SES students might suffer more from leisure ICT use than low-SES students in terms of reduced science achievement.

Even with this significant interaction effect, SES and leisure ICT use has no significant direct relationship, though positive ($r = 0.004$, $p > 0.1$; Table 2). This means that high-SES students actually do not engage in leisure ICT use more than low-SES students. The interaction effect implies the science achievement gap slightly shrinks between high- and low- SES students if they both engage in outside-school leisure ICT use.

Discussion

The conditioned ecological techno-process (CET) model works

This study extends the ecological theories of educational technology (e.g. Chiu 2019; Johnson 2010) to the CET model. The CET suggests that the quadratic effect of ICT use and SES are personal and social conditions, respectively, in the mesosystem that play roles in the effects of ICT use on learning outcomes (Figure 1). The empirical data support the CET model although only 1/4 of the total variance of the outcome is explained by the predictors (Table 3). This result is reasonable because only a limited number of predictors suggested by the CET model are included in this study. For example, potential predictors or conditioning moderators include the national technology policy in the exosystem and the pandemic crisis of COVID-19 in 2020, which increases educational technology or general ICT use, from the macrosystem.

The regression analysis results in this study reveal that SES direct effects as control were the most important contributor to the models for both mathematics and science achievements. However, even after controlling for the linear effects of SES and ICT availability, linear and quadratic effects of ICT use patterns and their slight interactions with SES predict achievements though with small effect size.

The three major findings are (1) for the linear relationships, both science and mathematics achievements are negatively predicted by outside-school leisure and inside-school ICT use patterns; mathematics achievement is positively predicted by outside-school educational ICT use. (2) For the quadratic relationships, the highest achievements in both mathematics and science are predicted by moderate frequent ICT use in all three patterns (rescaled IRT scores with higher scores representing more frequent ICT use; Figure 2). (3) For the moderation effect, SES may aggravate the negative effect of leisure ICT use on science achievement.

In summary, the findings support the CET model due to the quadratic effect of ICT use. However, only one moderation effect of SES occurs. The stable quadratic effect of ICT use on achievements deserves future research discovering the mechanism of self-regulation (Zimmerman 1990) and social regulation (Grau and Whitebread 2012) for this personal condition in human ICT use.

The following discussion will focus on the three findings, respectively, in detail and then conclude all the findings.

Linear effects: educational ICT Use benefits

Achievements are positively predicted by outside-school educational ICT use, negatively predicted by outside-school leisure ICT use, and weakly negatively predicted by school

ICT use (Table 3). The only exception is that outside-school educational ICT use positively predicts mathematics achievement but does not significantly predict science achievement. The findings are consistent with most of the results of previous studies (e.g. Kirschner and Karpinski 2010; Lee and Wu 2013).

The weak, negative effect of school ICT is disappointing. Although school ICT use is schoolwork-focused and supervised by teachers (Samuelsson 2010), the present quality of school ICT use appears to limit its benefits (Morgan 2010). Another reason may be that the PISA school ICT use items relate to the frequency of use for different purposes (e.g., browsing the Internet for schoolwork, using email, and playing simulations; Table 1). Using these items combined as a whole cannot reflect on the quality of school ICT use.

However, certain studies support the idea that ICT use in teaching can increase student achievements (Tamim et al. 2011), and this study further evaluated the nuances in ICT use patterns. The findings suggested that parent supervision may play a critical role in student educational or leisure ICT use outside school, which in turn influences achievements (Chiu 2019; Malamud and Pop-Eleches 2011).

The positive effects of educational ICT use on student achievements in mathematics may suggest that educational ICT use outside school may be an important criterion for high-quality schooling and parenting that can exceed school subject boundaries. Policymakers should raise public awareness about the role of parenting in student ICT use patterns and provide parents with behavior guidelines to ensure that ICT use at home has positive effects on achievements. Educators need to develop pedagogies to link inside and outside school ICT uses including educating parents on how to monitor their children's ICT use by focusing on educational ICT use related to schoolwork. Caution, however, should be made due to the relatively small direct effect of education ICT, compared with the stronger direct effect of SES. Implications for educational practice and policy should be interpreted with care until a further understanding of the small theoretical relationships revealed here is better understood.

Quadratic effects: moderate ICT Use benefits

This study finds stable quadratic effects of the three ICT use patterns on the two achievements. The finding means that moderate ICT use links to the best achievements. The quadratic effect is a missing conception in the literature and only partially indicated in Lei and Zhao (2007) study. As such, this study provides the initial empirical and theoretical basis for future research and suggests that educators develop moderate ICT-use pedagogies.

Based on these findings, educators may learn that moderate frequent ICT use plays an important role in ensuring enhanced achievements. Some examples of moderate ICT use pedagogies include recent innovations that mix traditional and ICT-use pedagogies such as blended learning (Porter et al. 2014) and flipped classrooms (Flumerfelt and Green 2013). Educators need to further create and elaborate on diverse forms of moderate ICT use pedagogies to optimize students' achievement. Educational policymakers need to implement policies that encourage parents and teachers to exercise moderate ICT use by stressing the role of moderate ICT use in maximizing students' achievements.

The above potentially important theoretical implications, however, are tentative indications of ways to improve practice. The quadratic effect of ICT use is small compared to the direct effect of SES (Table 3). Besides, the proportion of the achievement score explained (R^2) is low and few outliers with the highest negative ICT use scores may exaggerate the size of the effect (Figure 2). These limitations suggest that additional predictors need to be added to the model, perhaps predictors suggested by the CET model but have not been investigated in this study.

Interesting topics for future research include relationships between ICT use, cognitive outcomes, affective outcomes, and the interactions between the outcomes. Research indicates that ICT attitudes may precede ICT use (Celik and Yesilyurt 2013). Whether ICT attitudes precede ICT use and whether ICT attitudes mediate ICT use to affect achievements remain an unexplored topic. This can be investigated using path analysis and structural equation modeling techniques in future research. Going beyond the microsystem and mesosystem in the CET model, future research could incorporate more predictors from the other systems (e.g. national ICT policy in the exosystem) and investigate more complex relationships (e.g. multilevel).

SES moderates the effect of leisure ICT use on science achievement

The only SES moderation effect

SES significantly moderates the linear effects of leisure ICT use on science achievements in a negative direction (Table 3). This implies that the negative effects of leisure ICT use on achievements are stronger for high-SES students than for low-SES students. This reduces the gap in achievements between low- and high-SES students for high leisure ICT users (Figure 3).

This result can serve as a warning to high-SES families: Although SES positively predicts achievements (Table 3), it may be related to a reduced achievement if adolescents are allowed to indulge in leisure ICT use outside school. The results demonstrated a likely detrimental effect of leisure ICT use on achievements. For educational practice, parents are suggested to direct their children to engage in educational ICT use with cultural capital, supplying relevant and appropriate activities that suit children's interests and styles (Tondeur et al. 2010, 153). This parental educational support to their children's ICT use, however, may require support from schools.

The SES moderate effect, however, is small (Table 3) especially when compared to the variance of science achievement (Table 2; Figure 3). The theoretical value revealed here needs to be more fully investigated before such definite implications for practice and policy can safely be drawn.

The non-significant SES moderation effect

All the other moderating effects from SES are not significant (Table 3). This result seems to support the cumulative effect model (i.e. both advantaged and disadvantaged students benefit from an educational provision) more than the protective effect model (i.e. only disadvantaged students benefit from an educational provision; OECD, 2011: pp. 68 and 71). However, educational researchers warn that the moderating role of SES must be considered in evaluations of e-teaching remedial programs for low-SES students (Yang et al. 2013).

This study does not find SES to have a role in moderating the effect of school ICT use on achievements. The first reason may be that this study includes SES and ICT availability as controls in regression analyses so that the effect of school ICT use diminishes. However, this reason may not be true because the correlations between school ICT use and achievements are very low and non-significant (Table 2). The next speculation goes to educational practices that remedial programs by e-teaching for low-SES students have already resolved the problems of ICT use availability and pedagogical designs in Taiwan. Future research needs to examine this speculation by evaluation studies on e-teaching remedial programs.

For practical implications, although SES fails to play the other moderate effects, SES moderately strongly and directly links to achievements. School teachers still need to increase low-SES students' enjoyment and high-quality educational experiences using ICT at school and to develop pedagogies to transform low-SES students' ICT use experiences to higher achievements. Educational policymakers need to support this pattern of ICT use at school to decrease the digital gap due to SES.

Conclusion: contributions and limitations

Contributions

This study used regression analysis to analyze the effects of three ICT use patterns on science and mathematics achievements. The findings contribute to both educational knowledge and practices in three ways.

(1) The stable, though small, quadratic effects of ICT use on achievements are the most important finding of this study. This supports the posited CET model that a conditioned personal proximal process in the mesosystem. This study reveals that moderate ICT use tends to be the best choice for parents and educators. This is because moderate ICT use in different patterns (i.e. outside-school leisure and educational ICT uses and inside-school ICT use) generally relates to the highest achievements. Pedagogical innovations based on the moderate ICT use principle need to be developed in addition to existing potentially moderate ICT use pedagogies such as flipped classroom and blended learning.

(2) The small linear effects of the three ICT use patterns generally reproduce past research findings. Outside-school educational ICT use has a positive effect on mathematics achievements. Outside-school leisure ICT use has negative effects on science and mathematics achievements. The effects of school ICT use are weak and generally negative. However, the results encourage further evolution or reform of pedagogy in the microsystem (in the CET model) to increase the effect of ICT use on achievements. The trend of increased ICT use for education has generated new forms of pedagogies such as massive open online courses (Liyanagunawardena, Adams, and Williams 2013), technology-enhanced storytelling (Takacs, Swart, and Bus 2015), and virtual reality-based instruction (Merchant et al. 2014).

(3) Only one small SES moderation effect is identified, which gives minor support to the CET model with SES as a social condition in the mesosystem. This finding provides an important implication for educational practice: High-SES students may be more likely to worsen their science achievements by indulging in leisure ICT use more than low-SES students. High-SES parents should pay attention to their children's ICT use activities and focus on educational ICT use. Although SES fails to play the other moderate effects, SES moderately strongly and directly links to achievements. Teachers still need to increase low-SES students' enjoyment and high-quality educational experiences using ICT at school. Educational policymakers need to support this pattern of ICT use at school to decrease the digital gap due to SES.

Limitations

The limitations addressed in the above discussion mainly focus on the small effects of the major findings. The practical implication based on the findings needs to be validated by future research. The CET model can also be revised further if more evidence is obtained. Besides, this study has the following limitations that may be resolved by future research.

(1) ICT use for educational and non-educational purposes is increasing. Whether rapid changes in technology will change the linear and quadratic effects of diverse ICT use patterns on diverse learning outcomes remains an emerging issue. For example, this study suggests that moderate ICT use is the best choice given the results showing generally quadratic relationships between ICT use and achievements. Can the relationship change because ICT has become interwoven in all of our daily practices? Although this is a possibility, moderate ICT uses maybe still a 'best choice' if we return to see the influence of past technological advances (e.g. television) on education. Education that focuses on human beings and optimizes the interaction between human beings, nature, and technology will remain an important research topic in the future.

(2) The direct effect of SES is moderate but the moderation effect of SES is small and few (only for the direct effect of leisure ICT use on science achievement). Even with the support of the CET model (Figure 1), SES only plays one moderation role in achievement. One reason may be the unstable relationships of achievements with educational and school ICT use patterns. Future research can identify more effective ICT use patterns (like leisure ICT use) with achievement. In the chronosystem, the effects of SES moderation may change as ICT becomes more affordable to low-SES families. The digital divide may or may not be a response to social class division (Lee and Wu 2012; Tondeur et al. 2010). Social class division is slower and more difficult to change than technological advances. Nowadays, ICT advances tend to precede social class changes. Whether ICT advances will decrease or increase social class division, however, remains an unresolved question. Educators and educational policymakers still need to optimize the interactions between learners' learning outcomes and ICT uses and monitor ICT advances and affordability, especially for low-SES children and their parents in their respective societies.

(3) This study only focuses on simple regression analysis on certain measures in the microsystem and mesosystem of the CET model (Figure 1). When massive numbers

of predictors are included in the regression models as suggested by the multiple systems in the CET, other data analysis techniques such as machine learning may be an option.

(4) To validate the findings of this study, the methodology used in this study can be used to examine data from other cultures, longitudinal datasets, and other constructs of learning outcomes. For example, ICT attitudes, openness, and perseverance are affective outcomes addressed in the literature on educational technology (Roberts-Holmes 2014; Romero et al. 2013; Papastergiou 2010). Past literature has implied that leisure ICT use may be negatively correlated with perseverance and educational ICT use may positively relate to perseverance (Thompson 2013). School ICT use may reduce student perseverance by increasing multitasking and distraction (Sana, Weston, and Cepeda 2013).

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References

Angus, L., I. Snyder, and W. Sutherland-Smith. 2004. "ICT and Educational (Dis) Advantage: Families, Computers and Contemporary Social and Educational Inequalities." *British Journal of Sociology of Education* 25: 3–18. doi:10.1080/0142569032000155908.

Baeten, M., E. Kyndt, K. Struyven, and F. Dochy. 2010. "Using Student-centered Learning Environments to Stimulate Deep Approaches to Learning: Factors Encouraging or Discouraging Their Effectiveness." *Educational Research Review* 5: 243–260. doi:10.1016/j.edurev.2010.06.001.

Celik, V., and E. Yesilyurt. 2013. "Attitudes to Technology, Perceived Computer Self-efficacy and Computer Anxiety as Predictors of Computer Supported Education." *Computers & Education* 60: 148–158. doi:10.1016/j.compedu.2012.06.008.

Chiu, M.-S. 2019. "Exploring Models for Increasing the Effects of School Information and Communication Technology Use on Learning Outcomes through Outside-school Use and Socioeconomic Status Mediation: The Ecological Techno-Process." *Educational Technology Research and Development*. doi:10.1007/s11423-019-09707-x.

Chiu, M.-S., and D. Whitebread. 2011. "Taiwanese Teachers' Implementation of a New 'Constructivist Mathematics Curriculum': How Cognitive and Affective Issues are Addressed." *International Journal of Educational Development* 31: 196–206. doi:10.1016/j.ijedudev.2010.06.014.

Claro, M., D. D. Preiss, E. San Martín, I. Jara, J. E. Hinostroza, S. Valenzuela, F. Cortes, and M. Nussbaum. 2012. "Assessment of 21st Century ICT Skills in Chile: Test Design and Results from High School Level Students." *Computers & Education* 59: 1042–1053. doi:10.1016/j.compedu.2012.04.004.

Colvin, G. 2015. *Humans are Underrated: What High Achievers Know that Brilliant Machines Never Will*. New York: Portfolio/Penguin.

Dawson, J. F. 2014. "Moderation in Management Research: What, Why, When and How." *Journal of Business and Psychology* 29: 1–19. doi:10.1007/s10869-013-9308-7.

Flumerfelt, S., and G. Green. 2013. "Using Lean in the Flipped Classroom for at Risk Students." *Educational Technology & Society* 16: 356–366.

Fox, J., and S. Weisberg. 2011. *An {R} Companion to Applied Regression*. 2nd ed. Thousand Oaks CA: Sage. http://socserv.socsci.mcmaster.ca/jfox/Books/Companion

Grau, V., and D. Whitebread. 2012. "Self and Social Regulation of Learning during Collaborative Activities in the Classroom: The Interplay of Individual and Group Cognition." *Learning and Instruction* 22: 401–412. doi:10.1016/j.learninstruc.2012.03.003.

Gubbels, J., N. M. Swart, and M. A. Groen. 2020. "Everything in Moderation: ICT and Reading Performance of Dutch 15-year-olds." *Large-scale Assessments in Education* 8 (1): 1. doi:10.1186/s40536-020-0079-0.

Hair, J. F., Jr., W. C. Black, B. J. Babin, R. E. Anderson, and R. L. Tatham. 2006. *Multivariate Data Analysis*. 6th ed. Upper Saddle River, NJ: Prentice-Hall.

Hammond, M. 2014. "Introducing ICT in Schools in England: Rationale and Consequences." *British Journal of Educational Technology* 45: 191–201. doi:10.1111/bjet.12033.

Hinvest, N., and M. Brosnan. 2012. "Identifying Vulnerability Markers for Pathological Internet Use and Pathological Video-game Playing within an Educational Context." *Journal of Educational Computing Research* 46: 357–376. doi:10.2190/EC.46.4.c.

Hlavac, M. 2018. "Stargazer: Well-formatted Regression and Summary Statistics Tables." R package version 5.2.1. https://CRAN.R-project.org/package=stargazer

Johnson, G. 2010. "Internet Use and Child Development: The Techno-microsystem." *Australian Journal of Educational and Developmental Psychology* 10: 32–43.

Johnson, G. M., and P. Puplampu. 2008. "A Conceptual Framework for Understanding the Effect of the Internet on Child Development: The Ecological Techno-subsystem." *Canadian Journal of Learning and Technology* 34: 19–28.

Junco, R. 2012. "The Relationship between Frequency of Facebook Use, Participation in Facebook Activities, and Student Engagement." *Computers & Education* 58: 162–171. doi:10.1016/j.compedu.2011.08.004.

Junco, R., and S. R. Cotten. 2012. "No A 4 U: The Relationship between Multitasking and Academic Performance." *Computers & Education* 59: 505–514. doi:10.1016/j.compedu.2011.12.023.

Kent, N., and K. Facer. 2004. "Different Worlds? A Comparison of Young People's Home and School ICT Use." *Journal of Computer Assisted Learning* 20: 440–455. doi:10.1111/j.1365-2729.2004.00102.x.

Kirschner, P. A., and A. C. Karpinski. 2010. "Facebook® and Academic Performance." *Computers in Human Behavior* 26: 1237–1245. doi:10.1016/j.chb.2010.03.024.

Knofczynski, G. T., and D. Mundfrom. 2008. "Sample Sizes When Using Multiple Linear Regression for Prediction." *Educational and Psychological Measurement* 68: 431–442. doi:10.1177/0013164407310131.

Kozma, R. B. 2003. "Technology and Classroom Practices: An International Study." *Journal of Research on Technology in Education* 36: 1–14. doi:10.1080/15391523.2003.10782399.

Kubiatko, M., and K. Vlckova. 2010. "The Relationship between ICT Use and Science Knowledge for Czech Students: A Secondary Analysis of PISA 2006." *International Journal of Science and Mathematics Education* 8: 523–543. doi:10.1007/s10763-010-9195-6.

Lee, Y. H., and J. Y. Wu. 2012. "The Effect of Individual Differences in the Inner and Outer States of ICT on Engagement in Online Reading Activities and PISA 2009 Reading Literacy: Exploring the Relationship between the Old and New Reading Literacy." *Learning and Individual Differences* 22: 336–342. doi:10.1016/j.lindif.2012.01.007.

Lee, Y. H., and J. Y. Wu. 2013. “The Indirect Effects of Online Social Entertainment and Information Seeking Activities on Reading Literacy.” *Computers & Education* 67: 168–177. doi:10.1016/j.compedu.2013.03.001.

Lei, J., and Y. Zhao. 2007. “Technology Uses and Student Achievement: A Longitudinal Study.” *Computers & Education* 49: 284–296. doi:10.1016/j.compedu.2005.06.013.

Lim, C.-P., Y. Zhao, J. Tondeur, C.-S. Chai, and -C.-C. Tsai. 2013. “Bridging the Gap: Technology Trends and Use of Technology in Schools.” *Educational Technology & Society* 16: 59–68.

Lipsey, M. W., K. T. Nesbitt, D. C. Farran, N. Dong, M. W. Fuhs, and S. J. Wilson. 2017. “Learning-related Cognitive Self-regulation Measures for Prekindergarten Children: A Comparative Evaluation of the Educational Relevance of Selected Measures.” *Journal of Educational Psychology* 109: 1084–1102. doi:10.1037/edu0000203.

Liyanagunawardena, T. R., A. A. Adams, and S. A. Williams. 2013. “MOOCs: A Systematic Study of the Published Literature 2008-2012.” *International Review of Research in Open and Distributed Learning* 14: 202–227. doi:10.19173/irrodl.v14i3.1455.

Malamud, O., and C. Pop-Eleches. 2011. “Home Computer Use and the Development of Human Capital.” *The Quarterly Journal of Economics* 126: 987–1027. doi:10.1093/qje/qjr008.

Merchant, Z., E. T. Goetz, L. Cifuentes, W. Keeney-Kennicutt, and T. J. Davis. 2014. “Effectiveness of Virtual Reality-based Instruction on Students’ Learning Outcomes in K-12 and Higher Education: A Meta-analysis.” *Computers & Education* 70: 29–40. doi:10.1016/j.compedu.2013.07.033.

Morgan, A. 2010. “Interactive Whiteboards, Interactivity and Play in the Classroom with Children Aged Three to Seven Years.” *European Early Childhood Education Research Journal* 18: 93–104. doi:10.1080/13502930903520082.

Mumtaz, S. 2001. “Children’s Enjoyment and Perception of Computer Use in the Home and the School.” *Computers & Education* 36: 347–362. doi:10.1016/S0360-1315(01)00023-9.

Nasah, A., B. DaCosta, C. Kinsell, and S. Seok. 2010. “The Digital Literacy Debate: An Investigation of Digital Propensity and Information and Communication Technology.” *Educational Technology Research and Development* 58: 531–555. doi:10.1007/s11423-010-9151-8.

Organization for Economic Co-operation and Development. 2011. *Against the Odds: Disadvantaged Students Who Succeed in School*. PISA: OECD Publishing. doi:10.1787/9789264090873-en.

Organization for Economic Co-operation and Development. 2014. *PISA 2012 Technical Report*. PISA: OECD Publishing.

Paiva, J. C., C. Morais, and L. Moreira. 2017. “Activities with Parents on the Computer: An Ecological Framework.” *Journal of Educational Technology & Society* 20 (2): 1–14.

Papastergiou, M. 2010. “Enhancing Physical Education and Sport Science Students’ Self-efficacy and Attitudes regarding Information and Communication Technologies through a Computer Literacy Course.” *Computers & Education* 54: 298–308. doi:10.1016/j.compedu.2009.08.015.

Perveen, A. 2018. “Facilitating Multiple Intelligences through Multimodal Learning Analytics.” *Turkish Online Journal of Distance Education* 19: 18–30. doi:10.17718/tojde.382655.

Porter, W. W., C. R. Graham, K. A. Spring, and K. R. Welch. 2014. “Blended Learning in Higher Education: Institutional Adoption and Implementation.” *Computers & Education* 75: 185–195. doi:10.1016/j.compedu.2014.02.011.

Ravizza, S. M., D. Z. Hambrick, and K. M. Fenn. 2014. “Non-academic Internet Use in the Classroom Is Negatively Related to Classroom Learning Regardless of Intellectual Ability.” *Computers & Education* 78: 109–114. doi:10.1016/j.compedu.2014.05.007.

Roberts-Holmes, G. 2014. “Playful and Creative ICT Pedagogical Framing: A Nursery School Case Study.” *Early Child Development and Care* 184: 1–14. doi:10.1080/03004430.2013.772991.

Rodríguez, P., M. Nussbaum, and L. Dombrovskaia. 2012. “Evolutionary Development: A Model for the Design, Implementation, and Evaluation of ICT for Education Programs.” *Journal of Computer Assisted Learning* 28: 81–98. doi:10.1111/j.1365-2729.2011.00419.x.

Romero, M., M. Guitert, A. Sangrà, and M. Bullen. 2013. “Do UOC Students Fit in the Net Generation Profile? An Approach to Their Habits in ICT Use.” *The International Review of Research in Open and Distributed Learning* 14: 158–181. doi:10.19173/irrodl.v14i3.1422.

Ross, S. M., G. R. Morrison, and D. L. Lowther. 2010. "Educational Technology Research past and Present: Balancing Rigor and Relevance to Impact School Learning." *Contemporary Educational Technology* 1: 17–35.

Samuelsson, U. 2010. "ICT Use among 13-year-old Swedish Children." *Learning, Media and Technology* 35: 15–30. doi:10.1080/17439880903560936.

Sana, F., T. Weston, and N. J. Cepeda. 2013. "Laptop Multitasking Hinders Classroom Learning for Both Users and Nearby Peers." *Computers & Education* 62: 24–31. doi:10.1016/j.compedu.2012.10.003.

Selwyn, N., J. Potter, and S. Cranmer. 2009. "Primary Pupils' Use of Information and Communication Technologies at School and Home." *British Journal of Educational Technology* 40: 919–932. doi:10.1111/j.1467-8535.2008.00876.x.

Takacs, Z. K., E. K. Swart, and A. G. Bus. 2015. "Benefits and Pitfalls of Multimedia and Interactive Features in Technology-enhanced Storybooks: A Meta-analysis." *Review of Educational Research* 85: 698–739. doi:10.3102/0034654314566989.

Tamim, R. M., R. M. Bernard, E. Borokhovski, P. C. Abrami, and R. F. Schmid. 2011. "What Forty Years of Research Says about the Impact of Technology on Learning a Second-order Meta-analysis and Validation Study." *Review of Educational Research* 81: 4–28. doi:10.3102/0034654310393361.

Taylor, R. 1990. "Interpretation of the Correlation Coefficient: A Basic Review." *Journal of Diagnostic Medical Sonography* 6: 35–39. doi:10.1177/875647939000600106.

Thompson, P. 2013. "The Digital Natives as Learners: Technology Use Patterns and Approaches to Learning." *Computers & Education* 65: 12–33. doi:10.1016/j.compedu.2012.12.022.

Tømte, C., and O. E. Hatlevik. 2011. "Gender-differences in Self-efficacy ICT Related to Various ICT-user Profiles in Finland and Norway. How Do Self-efficacy, Gender and ICT-user Profiles Relate to Findings from PISA 2006." *Computers & Education* 57: 1416–1424. doi:10.1016/j.compedu.2010.12.011.

Tondeur, J., I. Sinnaeve, M. Van Houtte, and J. Van Braak. 2010. "ICT as Cultural Capital: The Relationship between Socioeconomic Status and the Computer-use Profile of Young People." *New Media & Society* 13: 151–168. doi:10.1177/1461444810369245.

Valentín, A., P. M. Mateos, M. M. González-Tablas, L. Pérez, E. López, and I. García. 2013. "Motivation and Learning Strategies in the Use of ICTs among University Students." *Computers & Education* 61: 52–58. doi:10.1016/j.compedu.2012.09.008.

Vekiri, I. 2010. "Socioeconomic Differences in Elementary Students' ICT Beliefs and Out-of-school Experiences." *Computers & Education* 54: 941–950. doi:10.1016/j.compedu.2009.09.029.

Vogel, F., C. Wecker, I. Kollar, and F. Fischer. 2017. "Socio-cognitive Scaffolding with Computer-supported Collaboration Scripts: A Meta-analysis." *Educational Psychology Review* 29: 477–511. doi:10.1007/s10648-016-9361-7.

Voogt, J., G. Knezek, M. Cox, D. Knezek, and A. Ten Brummelhuis. 2013. "Under Which Conditions Does ICT Have A Positive Effect on Teaching and Learning? A Call to Action." *Journal of Computer Assisted Learning* 29: 4–14. doi:10.1111/j.1365-2729.2011.00453.x.

Yang, Y., L. Zhang, J. Zeng, X. Pang, F. Lai, and S. Rozelle. 2013. "Computers and the Academic Performance of Elementary School-aged Girls in China's Poor Communities." *Computers & Education* 60: 335–346. doi:10.1016/j.compedu.2012.08.011.

Zimmerman, B. J. 1990. "Self-regulated Learning and Academic Achievement: An Overview." *Educational Psychologist* 25: 3–17. doi:10.1207/s15326985ep2501_2.

Appendix

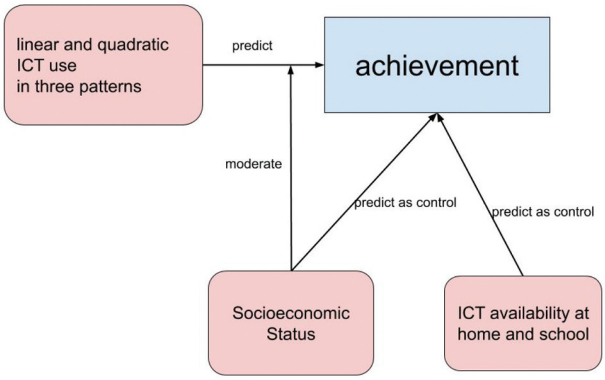

Figure A1. The diagrammatical model for the Research Question.

R codes

```
  # Create derived predictors.
library('dplyr')
twn3 <- mutate(twn3,
          leisureICT2 = leisureICT * leisureICT,
          educationICT2 = educationICT * educationICT,
          schoolICT2 = schoolICT * schoolICT,
          sesLeisureICT = ses * leisureICT,
          sesEducationICT = ses * educationICT,
          sesSchoolICT = ses * schoolICT,
          sesLeisureICT2 = ses * leisureICT2,
          sesEducationICT2 = ses * educationICT2,
          sesSchoolICT2 = ses * schoolICT2)
  # Mathematics achievement is regressed on 15 predictors (Model 1 in Table 3).
modelMathematics = lm(scale(twn3$mathematics) ~
          scale(twn3$ses)+scale(twn3$ictHome)+scale(twn3$ictSchool) #Predictors 1–3 (Table 3)
          +scale(twn3$leisureICT)+ scale(twn3$leisureICT2) #Predictors 4–5
          +scale(twn3$educationICT)+ scale(twn3$educationICT2) #Predictors 6–7
          +scale(twn3$schoolICT)+scale(twn3$schoolICT2) #Predictors 8–9
          +scale(twn3$sesLeisureICT)+scale(twn3$sesLeisureICT2) #Predictors 10–11
          +scale(twn3$sesEducationICT)+scale(twn3$sesEducationICT2) #Predictors 12–13
          +scale(twn3$sesSchoolICT)+scale(twn3$sesSchoolICT2) #Predictors 14–15,
          weights = twn3$weight)
summary(modelMathematics)
  # Science achievement is regressed on 15 predictors (Model 2 in Table 3).
modelScience = lm(scale(twn3$science) ~
          scale(twn3$ses)+scale(twn3$ictHome)+scale(twn3$ictSchool)
          +scale(twn3$leisureICT)+ scale(twn3$leisureICT2)
          +scale(twn3$educationICT)+ scale(twn3$educationICT2)
          +scale(twn3$schoolICT)+scale(twn3$schoolICT2)
          +scale(twn3$sesLeisureICT)+scale(twn3$sesLeisureICT2)
          +scale(twn3$sesEducationICT)+scale(twn3$sesEducationICT2)
          +scale(twn3$sesSchoolICT)+scale(twn3$sesSchoolICT2), weights = twn3$weight)
summary(modelScience)
```