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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

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Abstract

Based on the ecological theories of educational technology, this study explored models for effective information and communication technology (ICT) use on learning outcomes, mediated by outside-school ICT use and socioeconomic status (SES), using structural equation modeling (SEM). Four models were developed based on empirical findings and validated using the 2012 Taiwanese sample of the Program for International Student Assessment to demonstrate model exploration. The four models measure the effects of ICT use on learning outcomes from (A) parallel ICT use, (B) inside-school ICT use with outside-school ICT use mediation, (C) Model A with SES mediation, and (D) Model B with SES mediation. Data analysis results indicate that the four models fit empirical data; Models C and D (with SES mediation) are superior to Models A and B based on fit indices; Models A and B are superior to Models C and D based on information criteria; and Models B–D (with mediation) provide more educational meaning than does Model A (without mediation). The results suggest new variables (i.e. outside-school ICT use and SES) and a modeling technique focusing on mediation effects (i.e. SEM) may be used to promote educational technology development by improving the effect of inside-school ICT use on traditional learning outcomes.

Introduction

Schools have gradually incorporated information and communication technology (ICT) to address traditional curricula through educational activities inside school (i.e. 'inside-school ICT use' directly experienced by students for learning in this study). There are, however, diverse and uncertain effects of inside-school ICT use on traditional learning outcomes attempted by national curricula such as achievements (a major cognitive outcome) and attitudes (a major affective outcome) (Cristia et al. 2010; Tamim et al. 2011).

The diverse and uncertain effects of inside-school ICT use on traditional learning outcomes may result from three reasons. First, inside-school ICT use only has effects on ICT use related learning outcomes (e.g. ICT skills and ICT efficacy) but fails to relate to traditional learning outcomes, including achievements and attitudes in specific school subjects such as mathematics, science, and languages (Aesaert et al. 2015; Zhou 2016). Second, researchers are still in the process of developing measures for increasing the effects of inside-school ICT use (Siddiq et al. 2016). Third, most models for the effects of inside-school ICT use on learning outcomes are developed based on researchers' or teachers' experiences or ideas (Lim et al. 2013; Mama and Hennessy 2013). These idea-based models tend to depict a thorough structure of components focusing on understanding the phenomenon but lacking large-scale quantitative evaluations of the relationships between ICT use and learning outcomes. Experiments may help researchers prove the effectiveness of certain methods in increasing the effects of inside-school ICT use on student learning outcomes (Angeli and Tsaggari 2016). Conducting experiments, however, is time consuming, and replicating experimental results in different contexts is necessary to validate previous experimental results.

Inspired by the ecological theories of educational technology (Johnson 2010a, b) and the discovery mode for investigating children's ecological contexts (Bronfenbrenner and Morris 2006), this study used statistical methodology and structural equation modeling (SEM) in an exploratory way to identify the effectiveness of methods for increasing the effects of inside-school ICT use on traditional learning outcomes. SEM is traditionally used to validate theory-based models but may be used for model or theory development (Schnoll et al. 2004). An emerging field such as that explored in this study tends to have support by case studies (Auld and Johnson 2015) but lack support from evaluation studies using large-scale open-access quantitative data (Fariña et al. 2015).

The purpose of this study therefore was to use inside-school ICT use as the agent to demonstrate how SEM may be used to explore models for increasing the effects of inside-school ICT use on learning outcomes, based on empirical findings related to outside-school ICT use and socioeconomic status (SES), with a large-scale open-access dataset. This study may advance the knowledge of quantitative model exploration methodologies for increasing the effects of ICT use on traditional learning outcomes. In other words, this paper fits the aim and scope of the academic field on educational technology research and development, which advocates using analytics (e.g. building models or algorithms) to evaluate the effectiveness of educational technology to traditional educational outcomes and to increase its contribution. Traditional educational outcomes in both cognitive and affective aspects (e.g. achievement and attitudes) are one of the major criteria for evaluating educational technology designs (e.g. Ocumpaugh et al. 2016). Identifying suitable models (or algorithms) is one of the major challenges faced by the recent development and research on educational technology such as intelligent tutoring systems (Tempelaar et al. 2015), machine learning models, educational data mining, and learning analytics (Baker and Inventado 2014). This study starts from a traditional educational research background and uses an exploratory way to use SEM, aiming to bridge the gap between the traditional educational research and the recent development of data- or model-based educational technology.

The following literature review will firstly focus on the theoretical basis for proposing the models of this study. Next, the literature review will focus on the reasons why adding outside-school ICT use and SES into a model may increase the effects of inside-school ICT use on learning outcomes.

Literature review

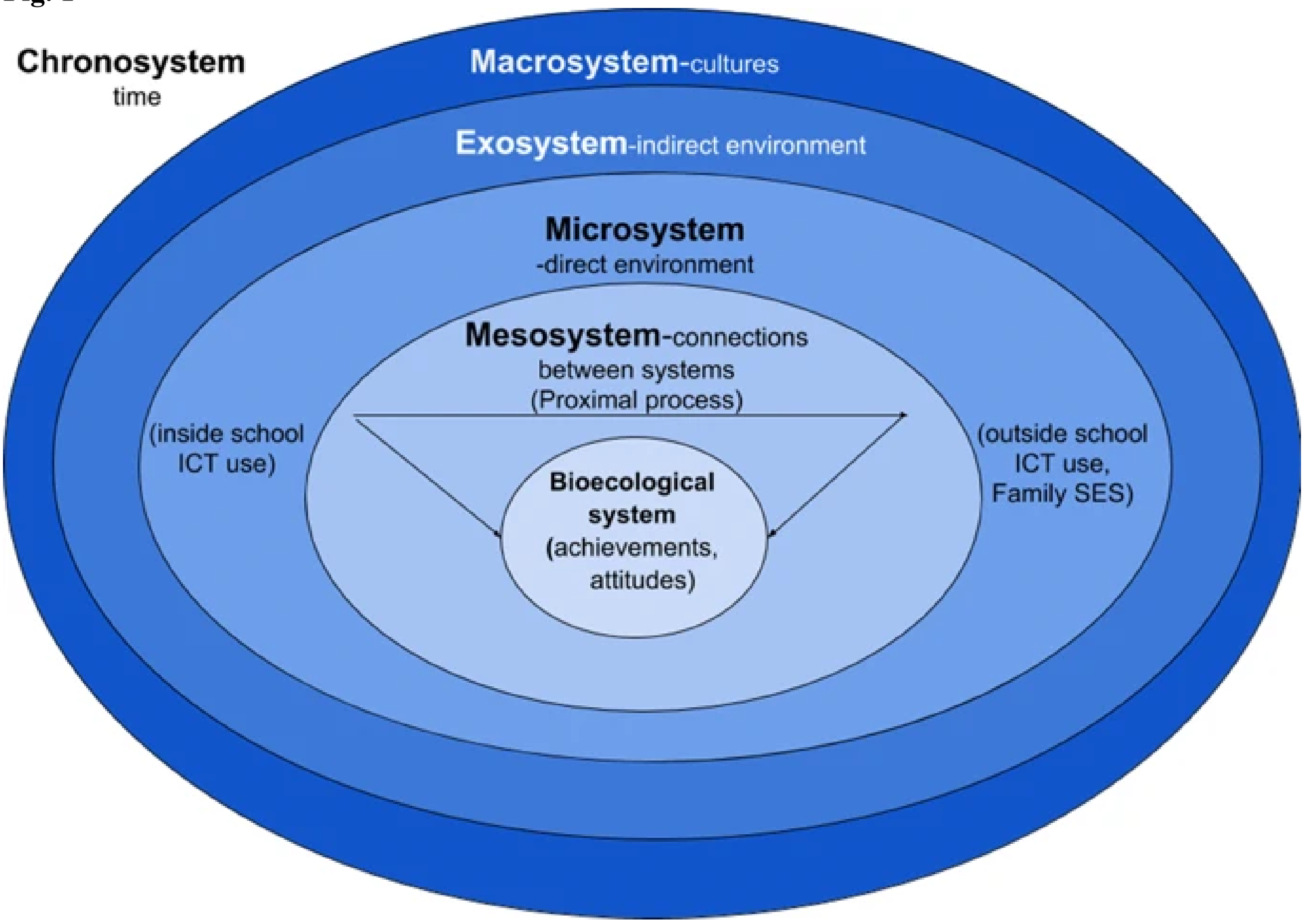
The ecological theories of educational technology

Increasing the effectiveness of educational technology needs to take account of multiple factors in students' ecological contexts. Based on Bronfenbrenner's (1979, 1989) ecological systems theory and bioecological model (Bronfenbrenner and Morris 2006; Johnson and Puplampu's (2008) ecological techno-microsystem highlights how children's development is influenced by the immediate environment (microsystem) of interacting with people (e.g. parents, teachers, and peers) on technology devices (e.g. computers, internet, e-books. and software). As a later development, Johnson (2010a) posits the ecological techno-microsystem, which elaborates the related components in the mechanism of how Internet use relates to child development: Children's learning outcome includes cognitive, emotional, social, and physical development; the contexts include technology use at school, home, and community; the patterns of technology use include communication, information, and recreation. A recent ecological framework, the "Activities with Parents on the Computer (APC)" networking frame, suggests that teachers' homework can serve as a leading role for inviting parental collaboration with their children in technology use (Paiva et al. 2017).

To use the terms in the ecological theories of educational technology for this study, SES is a factor in the microsystem, inside and outside school ICT use is part of the techno-subsystem, connecting inside and outside school ICT use is part of the mesosystem, cognitive and affective outcomes are part of the bioecological system (Johnson 2010b). Related studies have elaborated on the concepts in the theories. School ICT use or teachers' homework can play a leading role in inviting home ICT use with parental support, as suggested by the APC ecological framework, for both cognitive and affective aspects of learning and in both positive and negative directions (Paiva et al. 2017). Generally, children's self-report on internet use positively relates to children's social developments reported by parents and to cognitive developments reported by teachers, though with some negative relationships between children's developments and their instant messaging and playing games at school (Johnson 2010a). Children's cognitive development is more accounted for by Internet use than by SES (Johnson 2010b).

This study may be an extension of this line of research from using correlation or regression models to using SEM for the detailed mechanism or proximal process of how children interact with technology as a sub-microsystem. As suggested by the bioecological theory (Bronfenbrenner and Morris 2006) and the ecological techno-microsystem (Johnson 2010a), a focus on children's proximal processes is a later, mature development for the ecological theories on child development (Tudge et al. 2009). Based on the above ecological theories, this study posits a framework, the Ecological Techno-Process (ETP) to promote development (Fig. 1). Although the ETP can serve as a general framework, this study uses the ETP to guide the following literature review and propose the models to be examined; that is, this study only focuses on the proximal process (part of the mesosystem) for the bioecological and microsystem.

Fig. 1



The Ecological Techno-Process to promote development. The content inside () is examined in this study

Full size image ›

Outside-school ICT use may mediate the effects of inside-school ICT use on learning outcomes

Inside-school ICT use is a response to the worldwide trend of daily ICT use. The difference between inside-school and outside-school ICT use may be that most inside-school ICT use focuses on educational purposes under teacher supervision (Samuelsson 2010; Tondeur et al. 2007, 2010), whereas outside-school ICT use focuses more on leisure than educational purposes, with or without parental supervision (Malamud and Pop-Eleches 2011; Mumtaz 2001). The boundaries between inside-school and outside-school ICT use, however, appear to have gradually diminished because of recent developments and widespread use of online daily news, virtual social networks (Junco and Cotten 2012; Kent and Facer 2004), massive open online courses (Liyanagunawardena et al. 2013), and flipped classrooms (Flumerfelt and Green 2013; Roehl et al. 2013). For example, in flipped classrooms, students learn instructional content as homework through online lectures and the face-to-face classroom teaching can entirely focus on student-centered pedagogies such as cooperative and problem-based learning. Students can learn similar content and contact the same teachers and classmates through ICT in both inside-school and outside-school settings. This blurring of the boundary between inside-school and outside-school ICT use suggests that investing additional time in education or leisure outside-school ICT use may be related to learning outcomes. The thought is consistent with Hammond's (2014) suggestion that creating wide connections between inside-school and outside-school ICT use may benefit traditional learning outcomes.

The effects of inside-school ICT use on traditional cognitive learning outcomes (i.e. achievements) may be limited without ensuring teaching quality (Luu and Freeman 2011; Morgan 2010; Ravizza et al. 2014; Wurst et al. 2008). For affective learning outcomes, inside-school ICT use generally has positive relationships with attitudes toward ICT (Papastergiou 2010) and openness to new things (Selwyn, Potter, et al. 2009) but nonsignficant relationships with attendance (Muir-Herzig 2004) and negative relationships with concentration (Sana et al. 2013). Teachers use ICT with diverse ICT competences, classroom practices, conceptions, and beliefs (Mama and Hennessy 2013). Ensuring teaching quality of inside-school ICT use for desirable learning outcomes needs teacher ICT accessibility, competences, self-efficacy, adaptive teaching goals, and creative pedagogies; school technical and political support; and the whole ecological system support (Hammond 2014; Wang et al. 2014). Without ensuring teaching quality (perhaps as part of the reasons), large-scale quantitative studies tend to find diverse (no, positive, or negative) effects of inside-school ICT use on learning outcomes for different countries (Fariña et al. 2015).

Multiple case studies have demonstrated that student outside-school ICT use increases student competences addressed by the national curriculum. Student competences obtained by outside-school ICT use, however, may be hard to be assessed using traditional measures because of diverse patterns of student behaviors such as student security concerns, ICT use purposes, and passion spaces (Auld and Johnson 2015). On the other hand, quantitative survey studies generally find few or negative relationships between outside-school leisure ICT use and learning outcomes and slight positive relationships between outside-school educational ICT use and learning outcomes in domains such as computer science achievement and self-efficacy (Chen et al. 2014), reading (Fariña et al. 2015), and mathematics (Wu et al. 2016).

Socioeconomic status may mediate effects of ICT use on learning outcomes

SES is an index of a family's cultural and material capital and one of the key factors in ecological or sociocultural learning theories (Bronfenbrenner and Morris 2006; Lee 2016; Zeidler 2016). SES, therefore, is potentially related to ICT use outside school. Focusing on cultural capital, SES may help children focus on educational or advanced ICT use (Nasah et al. 2010; Vekiri 2010). Focusing on material capital, a high SES may result in access to ICT facilities without supervision or teaching, which may lead to leisure ICT use and limit learning outcomes (Selwyn and Gorard 2003; Tondeur et al. 2010). Relationships between SES and inside-school ICT use may be not strong in an educational system where public schools are well developed and most children attend public schools, as in Taiwan.

Research has long indicated that SES has stable relationships with learning outcomes such as achievements, interest, and openness to experiences, which may relate to cultural capital or gene (Tucker-Drob and Harden 2012). The stable relationships between SES and learning outcomes suggest that including SES as a predictor of achievement in a model is likely to increase model fit.

This predicted relationship between outside-school ICT use and SES combined with evidence-based relationships between SES and learning outcomes suggests that examining the relationship between ICT use and achievements without considering SES may be biased (Kubiatko and Vlckova 2010). As previous studies have indicated, outside-school ICT use, achievement, and SES are positively related (Lee and Wu 2012; Sánchez and Salinas 2008). SES, therefore, may mediate the effect of ICT use, particularly outside-school ICT use, on learning outcomes.

Research questions

The literature review reveals that the ecological theories of educational technology with a focus on the mechanism among the factors in students' contexts can address the complex relationships between diverse ICT use and traditional learning outcomes. In this study, the diverse patterns of ICT use include inside-school ICT use, outside-school leisure ICT use, and outside-school educational ICT use. The weak or diverse effects of inside-school ICT use on traditional learning outcomes suggest that increasing the effects of inside-school ICT use is necessary. This study therefore examined a model—without reference to empirical findings—as a reference model (Model A: parallel ICT use). Additionally, three models were developed based on empirical findings of links between inside-school and outside-school ICT use (Model B) and stable relationships between SES and learning outcomes (Models C–D). Four hypotheses were posited for gradually increasing the effects of inside-school ICT use on learning outcomes by accounting for mediated effects of outside-school ICT use and SES.

Hypothesis 1

Diverse ICT use (i.e. inside-school ICT use, outside-school leisure ICT use, and outside-school educational ICT use) has parallel, weak effects on learning outcomes (achievements and attitudes) (Model A).

Hypothesis 2

Diverse ICT use with additional mediated outside-school ICT use (i.e. the link between inside-school to outside-school ICT use) has increased effects on learning outcomes (Model B) compared with Model A.

Hypothesis 3

Diverse ICT use with additional SES mediation has increased effects on learning outcomes (Model C) compared with Model A.

Hypothesis 4

Diverse ICT use with additional mediated outside-school ICT use and SES has increased effects on learning outcomes (Model D) compared with Models A–C.

Methods

Data source and sample

This study used data of the Taiwanese sample from the main and ICT surveys of the Program for International Student Assessment (PISA) in 2012 (Organization for Economic Cooperation and Development [OECD] 2013a) to examine the hypotheses. PISA is a triennial survey examining 15-year-old student achievements in mathematics, reading, and science, and collects related student, parent, and school background data since 2000. The ICT survey was optional and focused on ICT availability, use, and attitudes.

The Taiwanese sample comprised data from 6046 students. PISA used a scientific sampling procedure to select the students in each participating country, which allowed the selected sample to represent the target population in the country (OECD 2014). As such, the methodology used in this study (cf. the statistical analysis section) could be applied to examine the models (hypotheses) using the student samples from the other countries. The rationales for using the Taiwan sample were that (1) the Taiwan sample had both the main and ICT survey data and (2) the author is a resident of Taiwan, which would facilitate the discussion of the results in this study because ICT use might be a cultural dependent issue. The limitation of sample selection is further discussed in the conclusion section of this study.

Measures

Learning outcome 1: achievement

Three achievement measures were used to represent student cognitive learning outcomes: mathematics achievement ("pv1math" in PISA 2012), reading achievement ("pv1read"), and science achievement ("pv1scie") in this study. OECD (2013a) used cognitive tests to assess students' mathematical, scientific, and reading literacy, mainly including domain content knowledge and skills. The test reliabilities for the Taiwanese data were .910,

.890, and .910 for mathematics, reading, and science achievements, respectively. The three measures were scaled using item response theory (IRT) to values of mean (*M*) = 500 and standard deviation (*SD*) = 100. Higher scores represented higher achievements (OECD 2014, pp. 159, 233–234).

Learning outcome 2: attitudes

Attitudes comprised two measures: openness (“openps”) and perseverance (“persev”). Openness comprised five items such as “I can handle a lot of information” and “I seek explanations for things.” Perseverance also comprised five items such as “When confronted with a problem, I do more than what is expected of me” and “I remain interested in the tasks that I start.” The internal reliabilities for the Taiwanese sample were .860 for openness and .840 for perseverance. Both measures were rated on a 5-point Likert scale from 1 (*very much like me*) to 5 (*not at all like me*) (OECD 2014, pp. 337, 425).

ICT use

ICT use entailed three measures: inside-school ICT use (“usesch”), outside-school leisure ICT use (“entuse”), and outside-school educational ICT use (“homsch”). Inside-school ICT use involved nine items asking students about how often they used computers at school for activities such as “using email at school”, “doing homework on a school computer” and “playing simulations at school.” Leisure ICT use entailed 10 items asking students how often they used computers outside school for activities such as “playing one-player games”, “browsing the Internet for fun (such as watching videos)” and “participating in social networks.” Educational ICT use involved seven items asking students how often they used computers outside school for the activities such as “browsing the Internet for schoolwork”, “using email for communication with other students about schoolwork” and “doing homework on the computer.” Students rated the items on a 5-point Likert scale from 1 (*never or hardly ever*) to 5 (*every day*). The internal reliability for the Taiwanese sample was .850 for inside-school ICT use, .830 for leisure ICT use, and .860 for educational ICT use (OECD 2014, pp. 338–340, 426–427).

Socioeconomic status

OECD (2014, pp. 55, 351–353) calculated the derived measure SES (“escs”) based on three items: (a) home possessions (family wealth, cultural possessions, educational resources, and books), (b) the highest occupational status of parents (job descriptions coded and transformed to an interval scale that could reflect the SES of occupations across countries), and (c) the highest parental education (years of schooling). The SES scores were the first principal component scores obtained by principal component analysis of the three items in order to reduce measure numbers and further standardized ($M = 0$; $SD = 1$) on the basis of OECD students’ responses. The internal reliability of the three items was .690 for the Taiwanese data. An internal reliability value of .690 was acceptable for social science research with only three items of distinct characteristics.

The measurements of attitudes, ICT use, and SES were scaled internationally using IRT to values of $M = 0$ and $SD = 1$. Higher scores represented higher degrees of each measure (OECD 2014, p. 312). The case numbers (*N*), means, *SD*s, and correlations among the nine measures for the Taiwanese data are presented in Table 1.

Table 1 Descriptive statistics and correlations between the measures

Full size table

Statistical analysis

The data were analyzed using R software Version 3.1.3 (R Core Team, http://www.R-project.org/). Descriptive statistics and Pearson’s bivariate correlations (Table 1) were obtained for a basic understanding of the measures using the R psych and stats packages. Absolute values of correlation coefficients below or equal to .350 indicate weak relationships, those from .360 to .670 indicate moderate relationships, and those from .680 to 1.000 indicate strong relationships (Taylor 1990). Before using structural equation modeling (SEM) to examine the hypotheses, the data were weighted using the total student weight (“W_FSTUWT”) and 80 replicate weights (“W_FSTR1-80”) with the R survey package. The weighting procedure involved accounting for the PISA sampling design and the analysis results could be used to characterize the population (Oberski 2014; OECD 2014).

The four hypotheses were examined using SEM with the R lavaan package (Rosseel 2012). Some of the measures had missing data, revealed by the numbers of cases used to determine the measures (Table 1). Missing data were handled using the full information maximum likelihood (FIML) estimation, which was superior to other methods (e.g. listwise deletion, pairwise deletion, and similar response pattern imputation) when SEM was used (Enders and Bandalos 2001). This study compared FIML with listwise deletion and found that both methods generated similar parameter estimate patterns (e.g. value direction and significance levels), but FIML generated more desirable fit index values than listwise deletion did.

The default parameters obtained using the R lavaan package included factor loadings, regressions, correlations, and intercepts (e.g. Models A–D in Figs. 1, 2). Regression coefficients were added to the regression formula to examine the significance levels of mediated or indirect effects (Baron and Kenny 1986; Rosseel 2015).

Fig. 2

Model A: A model for the effects of parallel ICT use on learning outcomes. Model B: A model for the effects of ICT use with additional inside- to outside-school ICT use on learning outcomes. Model C: A model for the effects of diverse types of ICT use with additional SES mediations on learning outcomes. Model D: A model for the effects of diverse types of ICT use with additional inside- to outside-school ICT use and SES mediations on learning outcomes. The underlined standardized parameter estimates are not significant at $p = .05$

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The metrics for the fit indices and information criteria were used to examine how Models A–D fitted the data and whether this corresponded with the hypotheses. The fit indices indicated the capacity of a model to reproduce the variance–covariance matrix of the data. The Chi square (χ^2) value, the traditional criterion, represented the deviance between the observed and model-implied variance–covariance matrices, with a nonsignficant χ^2 indicating a good fit. The χ^2 value was not a suitable metric in this study because of the large sample size (Bollen and Long 1993). The root mean square error of approximation (RMSEA) was developed based on the χ^2 adjusted for sample sizes and was considered one of the major metrics for determining the power of a whole SEM model (Thoemmes et al. 2010). Traditionally, RMSEA values below .050 or .080 were viewed as a sign of good model fit to the population. However, recently RMSEA tended to be proper to assess competing models, with a smaller RMSEA value representing a better model fit to the population (Hair et al. 2010). Similar to RMSEA, standardized root mean square residual (SRMR; i.e. the average standardized residual) was suitable for comparing competing models, with a smaller SRMR value representing a better model fit. The comparative fit index (CFI) and the Tucker–Lewis index (TLI; also named the nonnormed fit index) are based on the χ^2 adjusted for degrees of freedom. The CFI penalty for model complexity was considerably lower than the TLI although the CFI and TLI normally generated similar results. CFI and TLI values higher than .900 represent good model fit and higher values indicate better fit.

Information criteria were applied to compare competing (nested or nonnested) models with lower values, indicating models that fitted data better (Lewis et al. 2011). Information criteria were based on maximum likelihood estimation with the Akaike information criterion (AIC) adjusted for unbiased estimation, the Bayesian information criterion (BIC) adjusted for parameter numbers, and the sample-size adjusted BIC (aBIC) adjusted for parameter numbers and sample sizes. The BIC and aBIC favor simpler models than the AIC does (Patarapichayatham et al. 2012). When sample sizes are large, the aBIC performs higher in selecting models than does the AIC or BIC (Kim et al. 2015).

Results

Direct effects of ICT use on learning outcomes (Model A)

Model A highlighted that diverse ICT use had parallel but weak effects on learning outcomes (achievements and attitudes) without a strong basis in theory or empirical research (Fig. 2 and Table 2). The results obtained by SEM generally supported Hypothesis 1 in that the three ICT measures (inside-school ICT use, outside-school leisure ICT use, and outside-school educational ICT use) had weak, although significant, effects on learning outcomes, except for the nonsignificant effect of inside-school ICT use on attitudes (Fig. 2 and Table 2). Model A closely fitted the data, as indicated by the fit index values (RMSEA [90% Confidence Interval] .060 [.054–.066], SRMR = .019, CFI = .989, TLI = .979).

Table 2 Selected parameters, fit indices, and information criteria values for Models A–D

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The weak or nonsignificant effects of inside-school ICT use were not expected of educators but replicated some previous findings (Ravizza et al. 2014). Previous literature (e.g. Flumerfelt and Green 2013) and the slightly higher effects of outside-school ICT use than those of inside-school ICT use suggest that recent trends of linking inside-school and outside-school ICT use implied that an increased effect from inside-school ICT use might be obtained in conjunction with outside-school ICT use, as hypothesized in Model B. The result also implied that outside-school ICT use could drive inside-school ICT use and in turn increase the total effect of ICT use on learning outcomes. This study, however, focused on inside-school ICT use as the agent and the link from outside-school ICT to inside-school ICT use was not examined in this study but could be examined by future research using similar methodologies.

ICT use with inside-school to outside-school links (Model B)

Model B was similar to Model A but Model B had two additional paths from inside-school to outside-school leisure use and to educational ICT use and one interaction effect between outside-school leisure use and educational ICT use (Fig. 2 and Table 2). The values of the direct effects in Model B were the same as those in Model A, but Model B had two additional positive and significant paths from inside-school to outside-school leisure and educational ICT use, respectively. In addition, the two additional paths contributed to significant mediated effects by inside-school ICT use on learning outcomes through leisure and educational ICT use. The results of unchanged direct effects and additional mediated effects provided the meaningful educational message that diverse ICT use with additional effects from inside-school to outside-school ICT use had increased effects on learning outcomes (Model B) compared with those without inside-school to outside-school ICT use (Model A), which supports the prediction of Hypothesis 2.

Model B fitted the data closely, as revealed by the fit index values (RMSEA = .060, [.054–.066], SRMR = .019, CFI = .989, TLI = .977). Most fit index values remained unchanged from Model A to Model B, which suggested that Model B with two additional paths had a similar fit to that of Model A.

Information criteria, however, increased from Model A (AIC = 262,734.856; BIC = 262,882.413; aBIC = 262,812.503) to Model B (AIC = 262,748.855; BIC = 262,943.362; aBIC = 262,851.208). The results suggested that Model A fitted the data better than Model B did, possibly because Model A was simpler than Model B. As shown in Fig. 2, compared with Model A (a three-layer model), Model B moves school ICT use to the start place of the model; by this moving, Model B becomes a more complicated four-layer model and adds three parameter estimates: (1) the path from inside-school to outside-school leisure ICT use, (2) the path from inside-school to outside-school educational ICT use, and (3) the interaction effect between outside-school leisure use and educational ICT use.

The results from fit indices (e.g. RMSEA) and information criteria (e.g. aBIC) reveal that Model B (linking inside-school and outside-school ICT uses) is better than Model A (without the linking) in terms of fit indices; however, compared with the simpler Model A, the model complexity of Model B reduces the capacity of Model B to fit empirical data in terms of the information criteria (Patarapichayatham et al. 2012).

ICT use with SES mediation (Model C)

Model C was similar to Model A with additional SES mediation for the three types of ICT use (Fig. 2 and Table 2). A student’s SES had a moderate effect on achievements and a weak effect on attitudes. It could be significantly regressed on leisure and educational, but not on inside-school ICT use.

The direct effects of achievements or attitudes regressed on the three types of ICT use were reduced, except for the direct effect of attitudes regressed on leisure ICT use. The significance levels, however, remained unchanged from Model A to Model C. The reduction in direct effects but unchanged significant levels suggests that SES partially mediated the effects of the three types of ICT use on learning outcomes (Baron and Kenny 1986). The increased direct effect of attitudes regressed on leisure ICT use was a unique phenomenon, suggesting that including SES mediation increased the effect of leisure ICT use on attitudes.

The mediated effects from SES were significant, except for achievements and attitudes regressed on inside-school ICT use. The results provided direct evidence that SES mediated the effects of outside-school leisure and educational, not inside-school, ICT use on learning outcomes.

The values of the fit indices indicated that Model C fitted the data well (RMSEA = .057 [.051–.062], SRMR = .018, CFI = .988, TLI = .976). Compared with Model A (RMSEA = .060 [.054–.066], SRMR = .019, CFI = .989, TLI = .979), Model C had a reduced RMSEA and SRMR values and slightly lower CFI and TLI values. The results suggested that Model C (with SES mediation) was better than Model A (without SES mediation) especially because the RMSEA was one of the major metrics for determining the power of an SEM model (Thoemmes et al. 2010).

Information criteria, however, increased from Model A (AIC = 262,734.856; BIC = 262,882.413; aBIC = 262,812.503) to Model C (AIC = 276,542.400; BIC = 276,736.907; aBIC = 276,644.753). The results suggested that Model A fitted the data better than Model C did. Although fit indices favored Model C, information criteria favored Model A. As stated before, the reasons might be that the information criteria favored simpler models (e.g. Model A, without SES mediation).

ICT with inside-school and outside-school links and SES mediation (Model D)

Model D was similar to Model B with additional SES mediation for the effects of the three types of ICT use on learning outcomes and similar to Model C with an additional two paths from inside-school to outside-school ICT use (Fig. 2 and Table 2). The direct effect values of Model D were the same as those of Model C. Models B and D had the same values of leisure and educational ICT use regressed on inside-school ICT use. The results suggested that SES mediation and inside-school to outside-school links were independent in their effects on learning outcomes.

Models D and C have the same values of mediated effects from SES. The mediated effects from outside-school ICT use, however, was reduced from Models B to D, except for the increased mediated effects from leisure ICT use on the effect of inside-school ICT use on attitudes; the significance levels remained unchanged. The results suggested that SES had additional, partial mediated effects on the mediated effects from outside-school ICT use.

The fit index values revealed that Model D closely fitted the data (RMSEA = .057 [.051–.062], SRMR = .018, CFI = .989, TLI = .975). Model D was the most complex among Models A–D. Model D, however, fitted the data no worse than Model C did (same RMSEA and SRMR, slightly higher CFI, and slightly lower TLI values) and better than Models A–B did (lower RMSEA and SRMR, same CFI, and slightly lower TLI values). The reasons that Model D had the lowest TLI might be that the TLI strongly penalizes model complexity.

Information criteria, however, indicated that Model D was the worst among Models A–D because Model D had the highest information criteria values (AIC = 276,556.399; BIC = 276,797.856; aBIC = 276,683.458). The reason might be that the information criteria favor simpler models and, among Models A–D, Model D was the most complex, adding (1) SES mediation, rather than without the adding (Models A and B) and (2) links from inside-school to outside-school ICT uses, rather than seeing inside-school and outside-school ICT uses as having equal effects on learning outcomes (Models A and C).

Discussion

Based on the ecological theories of educational technology (e.g. Johnson 2010a, b; Johnson and Puplampu 2008), this study proposes the ETP framework (Fig. 1) and uses four models to investigate the mechanism among traditional educational outcomes (as a bioecological factor), ICT use (as part of the techno-subsystem), and SES (as part of the microsystem) in students’ contexts. The four models extend gradually from less to more emphasis on the complex relationships between the factors using SEM as the major methodology. This study extends past studies on the ecological theories of educational technology to more focusing on mechanism and proximal process (Bronfenbrenner and Morris 2006). This may have elaborated this line of research further by emphasizing the proximal process to promote children’s development by educational technology. Future studies can explore proximal processes between different ecological systems and different factors (e.g. gender in the bioecological system, community ICT use in the microsystem, and school ICT policies).

Weak effects of ICT use on traditional learning outcomes (Model A)

The parallel effects of diverse ICT use on traditional learning outcomes are generally weak, especially for the nonsignficant effect of inside-school ICT use on attitudes. The results are consistent with previous empirical research findings that ICT use has diverse effects on cognitive and affective outcomes (Cristia et al. 2010; Morgan 2010). The strong factor loadings of the latent achievements and attitudes leading to their respective outcome measures (e.g. mathematics and reading) reveal that the diverse ICT use effects on the outcome measures can be viewed as being similar, a result consistent with most past research findings for different domains (Chen et al. 2014; Fariña et al. 2015; Wu et al. 2016). Despite large investments in inside-school ICT use including hardware, software, and teacher training, the effects of inside-school ICT use on traditional learning outcomes are disappointing and must be amended.

The results of parallel ICT use on learning outcomes, however, suggest likely methods for increasing the effects of inside-school ICT use. The slightly higher correlations between outside-school ICT use and learning outcomes suggest linking inside-school to outside-school ICT use may increase the effect of inside-school ICT use. In addition, the relationships between the three types of ICT use are significant and positive (Table 1).

Increased effects of inside-school ICT use by linking inside-school to outside-school ICT use (Model B)

Model B increases the effects of inside-school ICT use on learning outcomes through significant mediated effects from outside-school ICT use, which provides additional meaning for educational practices. The SEM results reveal that inside-school ICT use leading to outside-school educational ICT use results in multiple positive learning outcomes. The effect of inside-school ICT use on attitudes can also be activated through mediated effects from outside-school leisure ICT use. The results are consistent with previous PISA 2009 findings, in that home ICT use relates to student achievements more than inside-school ICT use does (OECD 2011, p. 20). The findings of this study suggest that student learning outcomes may be affected by educational provisions linking inside-school and outside-school educational ICT use (Hammond 2014; Kent and Facer 2004). Teachers may need further professional development to integrate ICT into curricula, address course objectives, and link student inside-school and outside-school ICT use for educational purposes (Barrera-Osorio and Linden 2009; Wang et al. 2014).

Effectively linking inside-school and outside-school ICT use presents educators with several challenges, including overcoming digital inequality. Teachers must develop pedagogies to monitor student outside-school educational ICT use (Wellington 2001). Outside-school ICT competence and availability (e.g. smart phones) may influence inside-school ICT use (Plesch et al. 2013; Veira et al. 2014) and the influence increases with age (Selwyn, Boraschi, et al. 2009). Future research can also examine a reverse model from outside-school to inside-school ICT use, as suggested by past case studies that through outside-school ICT use, students demonstrate increases in competencies addressed by the national curriculum (Auld and Johnson 2015).

A closer look at the present results reveals that the inside- and outside-school ICT links exaggerate the effects of school ICT use on achievements in both positive (via leisure ICT uses) and negative directions (via educational ICT use; Model B in Fig. 2). The result suggests that how people use technology, not technology use per se, matters (Lemma 2015). In other words, simply increasing the amount of time children spend on ICT use from inside school to outside school does not mean a positive effect on learning outcomes. Educators need to design high-quality pedagogies to link inside- and outside-school ICT uses (Hammond 2014; Wang et al. 2014). This study provides large-scale empirical evidence and demonstrates a methodology to validate the hypothesis of linking inside- and outside school ICT use, as suggested by the ecological APC framework (Paiva et al. 2017). This validated effectiveness of inside- to outside-school path routes may provide an initial basis for developing related pedagogies. In addition, the methodology used in this study can serve as a measure to evaluate the effectiveness of the new pedagogies designed on the basis of the inside- to outside-school ICT use principle.

SES mediation increases effects of ICT use on learning outcomes (Models C and D)

The second method for increasing the effect of ICT use is to add measures stably relating to learning outcomes. A student's SES has long been a well-known factor relating to achievements (Tucker-Drob and Harden 2012), which also relates to home ICT use (Tondeur et al. 2010). As predicted, the degrees of fit of the data increase by including SES (Models C and D) into the original models of parallel ICT use (Model A) or parallel with linking inside-school to outside-school ICT use (Model B). Educational ICT use with SES mediation increases additional positive effects and leisure ICT use with SES mediation increases additional negative effects.

The complete mediation model (Model D) provides meaningful lessons for both teachers and parents. Parents must monitor student outside-school ICT use and teachers may have to become nodes for distributed learning economies, connecting parents of different SESs through ICT use to optimize learning outcomes (Hohlfeld et al. 2010).

Another interesting issue to address is that: Will the effect of SES mediation identified by this study diminish because of the increase in ICT affordability? For the material capital of SES, the answer may be yes. Digital division due to SES is likely to gradually diminish because ICT equipment is much affordable for most families and schools nowadays in countries like Taiwan. School can also provide students computers to take home. For the cultural capital of SES, the answer is uncertain. As indicated by this study, the effects of outside-school ICT use can be exaggerated through SES mediation in both negative and positive directions: Outside-school leisure ICT use through SES mediation has negative effects on both achievements and attitudes; in contrast, outside-school educational ICT use through SES mediation has positive effects (Model D; Table 2). The results imply that the cultural capital of SES plays roles not only in the provision of traditional educational resources (e.g. parental academic support and experiences) but also that of outside-school ICT use (Nasah et al. 2010; Tondeur et al. 2010; Vekiri 2010).

Following this line of thought, it remains a question whether the stable relationships between SES and achievements (Tucker-Drob and Harden 2012) can decrease because of ICT equipment affordability. The answer, however, appears to be certain that digital era provides another chance to break the SES cycle in terms of traditional learning outcomes (e.g. achievements) and "educational ICT use" is the key. Future research can examine the longitudinal trend of the SES mediation effect identified in this study along the fast ICT development with a special focus on separating the effects from the material and cultural capital of SES.

Similar to related study findings, PISA 2012 results reveal a stable relationship between SES and achievement, with SES explaining 14.6% of the student achievement variance and 71% of the between-school achievement variance (OECD 2013b, pp. 34–38). High-SES students still have slightly more ICT facilities than low-SES students do. Despite the above general trend, there remain differences in the degrees of the SES-achievement relationships across countries. The generalizability of the models examined in this study may be partially determined by the different degrees of the relationships between SES and achievement. For example, among the countries participating in the PISA 2012 study, Taiwan and New Zealand have the strongest SES-achievement relationships, which may increase the possibility that the models examined in this study fit the empirical data. For countries with low or non-significant SES-achievement relationships such as Australia, Canada, and Estonia, the effects of SES mediation may reduce or diminish. For countries with strong SES-achievement relationships, national efforts to increase educational equality is especially needed perhaps through innovative pedagogies linking inside-school and outside-school ICT use suggested by this study.

SEM as a model exploration technique

ICT use is a new field and gradually spreading in both daily and educational lives, which offers opportunities to develop new models by applying diverse methodologies.

New theories, models or frameworks on ICT use in education is gradually emerging. For example, the technological pedagogical content knowledge (TPCK) framework focuses on teachers' knowledge of technology, pedagogy, and domain contents (Mishra and Koehler 2006). The community of inquiry (CoI) framework emphasizes that effective teaching require interdependence between social, cognitive and teaching presences (Garrison and Arbaugh 2007). The substitution augmentation modification redefinition (SAMR) model proposes that the four categories of ICT-infused instructional designs (i.e. SAMR) can promote lower- to higher-order learning outcomes (Puentedura 2014). All the models have their relative emphases, but mostly start from conceptual categories, base their models on teachers' professional development, and then to invite empirical evidence for supporting their models by case studies (Hamilton et al. 2016).

This study uses a different approach to model development. Several models are proposed on the basis of past research findings; the proposed models focus on learners' characteristics, ICT use experiences, and learning outcomes; large-scale survey data are used to directly examine the proposed models with SEM. SEM has traditionally been a model validation technique. This study used SEM as a model exploration technique, developing models—with support from empirical ICT use research findings—and validating models. This new approach may supplement the emerging theories on ICT use pedagogies by indicating new variables (e.g. SES), suggesting new pedagogies (i.e. linking inside-school and outside-school ICT uses), and proposing a new methodology for model development (i.e. SEM). For example, future research can validate the hierarchical structure of the different ICT uses and their respective learning outcomes predicted by the SAMR model (Puentedura 2014) using large-scale empirical data with SEM or the other data analysis techniques (e.g. multilevel analysis). The effective pedagogy identified in this study (i.e. linking inside-school and outside-school ICT uses) can be delineated by the four levels of ICT uses suggested by the SAMR model or can add to the CoI framework (Garrison and Arbaugh 2007).

This study used two methods for assessing model goodness-of-fit to data: fit indices and information criteria. Fit indices were developed based on χ^2 metrics, testing variance–covariance matrices between the observed and model-implied data. Information criteria were developed from the maximum likelihood estimation for comparing models.

Fit indices were found to provide a higher number of diverse functions than information criteria did. Fit indices can be used to determine degrees of fit to data for a single model (Hair et al. 2010) and the deviance between two models in fit index values can be used to compare the relative power of the two models, despite lacking salient statistical examination (Thoemmes et al. 2010). Previous research suggested using differences between the χ^2 values to compare two models (Cheong et al. 2003), but this cannot be used when two models have the same degrees of freedom (e.g. Models A and B in this study). Future research may develop statistical methods for using other fit indices (e.g. RMSEA) to compare models.

Information criteria can be used only to compare models. Information criteria appear to be sensitive to model complexity, with models that are more complex having higher information criteria values. As revealed in this study, Model A has the lowest information criteria values among Models A–D, which indicates Model A is the best model. Models B–D, however, provide messages that are more meaningful for educational practices but still have good or even better fit to the data, as revealed by the fit index values. Future information criteria development may revise penalty methods for model complexity.

Conclusion

Contributions and implications

This analytical paper evaluates models of how students' learning outcomes can be enhanced by ICT uses and SES using the SEM technique, which elaborates the mechanism or proximal process in children's microsystem based on the ecological theories of educational technology (Fig. 1). Traditionally used for theory validation, SEM proved to be a useful technique for model exploration (development and validation) in this study for the effects of ICT use, which is a new research field that lacks a strong theoretical basis. Four models were developed: Examining Model A with the least empirical research basis revealed that parallel ICT use (especially inside-school ICT use) has weak effects on learning outcomes. Model B has additional inside-school to outside-school ICT use effects, which provide additional mediated effects from outside-school ICT use and increase the effects of inside-school ICT use. Models C and D add additional SES mediation and thus increase the effects of inside-school ICT use in Models A and B, respectively because SES has a stable relationship with achievements, according to empirical research findings.

The SEM results obtained using fit indices reveal that Models C and D (with SES mediation) fit data better than Models A and B do (without SES mediation). The SEM results derived using information criteria reveal that information criteria favor simpler models (e.g. Model A being the simplest and Model D the most complex). The results imply that models with additional evidence-based mediators (e.g. SES and outside-school ICT use) can increase model fit and educational meaning, through increased model complexity.

This study provides new information and insights of content knowledge (what) and procedural knowledge (how) for educational technology development. First, outside-school ICT use and SES are two critical content variables that should be included or considered in educational technology designs in order to increase the effect of inside-school ICT use on traditional learning outcome. This inclusion will compensate for the unfavorable findings indicating uncertain, diverse effects of inside-school ICT use on traditional learning outcomes, which are intended to be achieved by the national curriculum designed by professionals in the traditional domains of knowledge in culture. Second, SEM can be part of the algorithm to develop educational technology in order to involve the concept of human psychological constructs and mediation effects. The SEM methodology is widely used by educational researchers to validate educational and psychological theories focusing on modeling mediation effects and latent constructs. Traditional learning outcomes are also psychological constructs and may be better addressed by a methodology using latent constructs (e.g. SEM) than a methodology using manifest variables (e.g. regression and cluster analyses).

The two insights regarding the content and procedural knowledge provided by this study provide a further insight into the practice of educational technology development: Link educational technology development (a new domain) with data, theories, and methodologies from educational studies (a traditional domain). Traditional learning outcomes as indicated by the national curriculum are values from cultural heritages and educational studies. Educational researchers have also defined and will continuously identify critical variables (e.g. SES, self-regulation, and confidence) highly related to traditional learning outcomes. The cross-disciplinary interaction between traditional educational research and educational technology research (e.g. providing the big, high-quality and empirical data and the content and procedural knowledge for each other) creates an avenue for sustainable development of both domains and future educational practices where technology use will be a daily routine.

Limitations and future research

This study has limitations because it uses a dataset from a specific culture (i.e. Taiwan) to structurally model a limited number of effects (e.g. those of outside-school leisure ICT use and SES) and learning outcomes (e.g. achievements and openness). Future research needs to consider all these limitations.

Firstly, the effective models identified in this study may be specific to a culture or a time. For example, mobile technology has become much more popular than before in Taiwan and some places in the world. The fast changes in educational technology merit future research to examine whether linking inside- to outside-school ICT uses remains an effective pedagogy and SES mediates the effects. The longitudinal trend of these effects also merits an investigation for different cultural contexts. For example, there may be different trends between a culture welcoming more educational technology and a culture welcoming less.

Secondly, future research can increase dialogues between educational technology researchers and traditional educational researchers to identify and incorporate the other critical factors (e.g. self-regulation and confidence) into related algorithms for addressing traditional learning outcomes. Related innovations of applying technology to instructional development may include an adaptive problem-posing system that can provide students suitable problems to suit students' levels of abilities, SES, confidence, and self-regulation. The innovation of educational technology also needs to include the formative assessment that can access students' synchronous and asynchronous cognitive and affective responses, monitor their progress, and automatically provide suitable problems.

Thirdly, the achievement measure comprises three major academic domains in school: mathematics, reading, and science; the other measures (e.g. attitudes and ICT use) are not domain specific. As such, empirical data from academic domains may fit the models examined in this study more than those from non-academic ones (e.g. music and physical education) do. Further, this study focuses on students' learning outcomes (i.e. achievements in three academic domains and attitudes such as openness and perseverance) and ignore social and emotional ones. Cautions have to be exercised given the likely negative impact of ICT use on students' self, interpersonal relationships, well-being, rights, and protection (Livingstone et al. 2015; Turkle 2011). Educators and educational technology designers need to consider children's development of self, well-being and interpersonal relationships when developing ICT-infused pedagogies and systems such as those involving cooperative learning and parent–child interactions (Johnston et al. 2015).

Fourthly, this study use statistical methods to investigate the effects of students' ICT use on learning outcomes with most data relying on students' self-report although the sample size is large. Only experimental-control designs, though mostly with small sample sizes, can justify a cause-effect claim. Further, as stated in the literature review (e.g. Morgan 2010; Ravizza et al. 2014), teachers' quality of ICT-infused instruction is the key to determining the effects of inside-school ICT use on traditional learning outcomes. This study only focuses on one pedagogical design (i.e. linking inside- and outside-school ICT uses) though with sufficient ICT-use measures for both outside-school ICT use (10 + 7 items) and inside-school ICT use (nine items) designed by the PISA (cf. the Measures section; Johnson 2010a, b). Further meaningful results can be obtained and models can be proposed and examined if detailed data are collected from observing teachers' instruction using ICTs in real educational settings. Another solution is to include survey items asking students or teachers their behaviors and perceptions about teachers' ICT-infused pedagogical designs. Large-scale survey studies (e.g. PISA) have included some ICT use items (such as "playing simulations at school" in PISA 2012 used in this study). Future research need to include more detailed, meaningful survey items about ICT-infused pedagogies (such as "How often do you work together with your peers as a team on providing multiple solutions to a mathematical problem on an online social network platform"). This will fit the world trend that ICT infrastructure becomes much affordable and available in the society, ICT use becomes much necessary in our new generations' daily lives, and thus ICT use in education becomes a normal practice.

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Ethics declarations

Conflict of interest

The authors declare that they have no conflict of interest

Ethical approval

This study used open data freely available to the public. The data source and sample were fully acknowledged in the paper.

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