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Adolescent students' perceived information and communication technology (ICT) competence and autonomy: Examining links to dispositions toward science in 42 countries

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ABSTRACT

A growing body of research has examined the relations of dispositions toward information and communication technology (ICT) to science achievement among adolescent students. However, there is little research exploring the associations between ICT-related dispositions and science-related dispositions among adolescent students. Therefore, this study, employing a self-determination theory perspective, investigated the relationships of perceived competence in ICT usage and perceived autonomy related to ICT usage with dispositions toward science—enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science—among 258,192 adolescent students from 10,767 schools in 42 PISA 2015 participating countries. Results of multilevel structural equation modeling (MSEM) analyses, after accounting for student-, school-, and country-level demographic characteristics, indicated that students' perceived competence in ICT usage and perceived autonomy related to ICT usage were significantly positively related to their enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science. Further, the results of the study revealed that students' perceived autonomy related to ICT usage was more strongly associated with their dispositions toward science than perceived competence in ICT usage. Implications of the findings for policy and practice are discussed.

1. Introduction

A growing corpus of research has examined the relations of availability and use of information and communication technologies (ICTs) at home and school to academic achievement among school children (e.g., Comi, Argentin, Gui, Origo, & Pagani, 2017; De Witte & Rogge, 2014; Erdogdu & Erdogdu, 2015; Hu, Gong, Lai, & Leung, 2018; Luu & Freeman, 2011; Salomon & Ben-David Kolikant, 2016; Scherer, Rohatgi, & Hatlevik, 2017; Skryabin, Zhang, Liu, & Zhang, 2015). A small but growing body of research has also investigated the associations of ICT-related dispositions, such as ICT self-efficacy and interest in ICT, with academic achievement among school children (e.g., Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014; Hatlevik, Throndsen, Loi, & Gudmundsdottir, 2018; Hu et al., 2018; Luu & Freeman, 2011; Rohatgi, Scherer, & Hatlevik, 2016). However, the majority of these studies yielded a mixed bag of findings, leading to inconclusive evidence on the relationships of availability and use of ICTs at home and school and ICT-related dispositions with academic achievement among school children.

Nonetheless, to the best of our knowledge, no study to date has explored the associations between ICT-related dispositions, such as perceived competence in ICT usage and perceived autonomy related to ICT usage, and science-related dispositions, such as enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science (i.e., conceptions of the nature of science), among adolescent students. Perceived competence in ICT usage refers to one's own beliefs about one's own competence in using digital media and digital devices, including desktop computers, portable laptops, notebooks, smartphones, tablet computers, cell phones without Internet access, game consoles, and Internet-connected television. Perceived autonomy related to ICT usage, on the other hand, refers to one's perceptions of personal independence (i.e., lack of external constraints or controls) in competently using digital media and digital devices, including desktop computers, portable laptops, notebooks, smartphones, tablet computers, cell phones without Internet access, game consoles, and Internet-connected television. Because a growing number of K-12 schools across the world are currently implementing integrative science, technology, engineering, and mathematics (STEM)

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education programs (Freeman, Marginson, & Tytler, 2014), it is vitally crucial for K-12 students to demonstrate high levels of competence and autonomy in using ICTs. Hence, the present study, employing a self-determination theory (Deci & Ryan, 1985, 2002, 2008; Ryan & Deci, 2000, 2017) perspective, aimed at examining the relations of perceived competence in ICT usage and perceived autonomy related to ICT usage to enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science among nationally representative samples of adolescent students drawn from schools in 42 countries. Given the crucial role that STEM education may play in technological adaptation, research-based innovation, and economic growth and productivity in countries across the globe (see Freeman, , Marginson, , & Tytler, 2014; Peri, Shih, & Sparber, 2015); and the dwindling numbers of students choosing to study STEM disciplines and entering STEM career fields across the world (see Jones et al., 2018; Marginson, Tytler, Freeman, & Roberts, 2013; Murphy, MacDonald, Danaia, & Wang, 2018; Smith & White, 2018), it is of critical importance to investigate whether or not positive dispositions toward ICT are related to positive dispositions toward science among adolescent students.

Furthermore, because positive dispositions toward science tend to correlate positively with gains in adolescent student science achievement (see Areepattamannil, Freeman, & Klinger, 2011; Areepattamannil & Kaur, 2013; Jansen, Scherer, & Schroeders, 2015), it is crucial to examine the proximal correlates of science-related dispositions among adolescent students. Nevertheless, in this era of ICT-enabled learning, hitherto research exploring the proximal correlates of science-related dispositions, unfortunately, failed to take into account the role of ICT-related dispositions in predicting science-related dispositions among adolescent students. Prior studies, however, have documented the ways in which ICT-rich learning environments can support pedagogical and curriculum innovations to enable learning of science among school children (see Cox & Webb, 2004; Webb, 2005). Although students who hold positive dispositions toward ICT are more likely to learn science better in an ICT-supported learning environment (see Kanematsu & Barry, 2016; Luu & Freeman, 2011), how well ICT-related dispositions interact with science-related dispositions to affect science achievement is still largely unknown. However, prior to examining the ways in which ICT-related dispositions interact with science-related dispositions to affect science achievement, it is mandatory to investigate the relationships between ICT-related dispositions and science-related dispositions. Indeed, a better understanding of the relationships between ICT-related dispositions and science-related dispositions is warranted to gauge the relative importance of different ICT-related dispositions in predicting science-related dispositions. Moreover, findings of such an investigation may help design and implement appropriate educational interventions that are capable of promoting positive dispositions toward ICT among adolescent students, which, in turn, may help develop their positive dispositions toward science. Self-determination theory can provide a useful framework for understanding the relationships between ICT-related dispositions and science-related dispositions.

2. Theoretical framework

Self-determination theory is “an empirically based, organismic theory of human behavior and personality development. The theory examines how biological, social, and cultural conditions either enhance or undermine the inherent human capacities for psychological growth, engagement, and wellness, both in general and in specific domains and endeavors” (Ryan & Deci, 2017, p. 3). The theory consists of six interrelated mini-theories: cognitive evaluation theory, organismic integration theory, causality orientations theory, basic psychological needs theory, goal contents theory, and relationships motivation theory (see Ryan & Deci, 2017). The cognitive evaluation theory explains the effects of extrinsic factors or social contextual events (e.g., competition, deadlines, evaluations, imposed goals, praise, rewards) on intrinsic motivation, behavior, and experience (Deci, 1975; Deci & Ryan, 1985). It is most useful for studying behavior for which people exhibit some interest or motivation (Ryan & Deci, 2000). The organismic integration theory proposes that externally regulated behaviors can be transformed into self-regulated behaviors (Deci & Ryan, 2002). It addresses the concept of internalization especially with respect to the development of extrinsic motivation (Deci & Ryan, 2002). The causality orientations theory, formulated to address individual differences in global (personality-level) motivational orientations, describes how people incorporate social influences into their motivational styles (Deci & Ryan, 1985, 2002). The basic psychological needs theory specifies a set of universal basic psychological needs that are essential nutrients for human beings' optimal development and functioning—psychological and physical health and social wellness (Deci & Ryan, 2002). The goal contents theory explains the impact of intrinsic and extrinsic goals on human motivation and wellness (Kasser & Ryan, 1996). Finally, the relationships motivation theory posits that the individuals’ ability to experience both positivity or regard and respect for autonomy is indispensable for developing high-quality interpersonal relationships (Ryan & Deci, 2017).

One of the six mini-theories within the self-determination theory, basic psychological needs theory, postulates that there are three basic psychological needs: the needs for autonomy, competence, and relatedness (Ryan & Deci, 2017). The need for autonomy refers to the need of individuals to engage in self-directed, self-regulating, and volitional behaviors to experience self-endorsement and ownership of their actions (Deci & Ryan, 2000; Ryan & Deci, 2017). The need for competence refers to the need of individuals to experience opportunities and supports for the exercise, expansion, and expression of their skills, abilities, or talents (Ryan & Deci, 2017). The need for relatedness refers to the need of individuals to experience opportunities to feel a sense of belongingness and connectedness (Deci & Ryan, 2000; Ryan & Deci, 2017). The proponents of self-determination theory posit that these three basic psychological needs are “salient themes in human nature and that practices and values that undermine or thwart their expression and satisfaction expectably yield developmental and social dysfunction and ill-being” (Ryan & Deci, 2017, p. 85). They further assert that the satisfaction of basic psychological needs for autonomy, competence, and relatedness in autonomy-supportive, competence-supportive, and relationally supportive social environments would facilitate enhancement of intrinsic motivational processes, internalization and integration of appropriate extrinsic behavioral regulations (i.e., extrinsically motivated activities) into self-regulation, and higher levels of autonomous causality orientations (Ryan & Deci, 2017).

Although no study to date has employed a self-determination theory framework to explicate and illuminate the relationships between ICT-related dispositions and science-related dispositions, a large body of research has demonstrated the positive associations of autonomy and competence needs with a myriad of academic dispositions and outcomes among school children across the world (see Liu, Wang, & Ryan, 2016; Ryan & Deci, 2017; Wehmeyer, Shogren, Little, & Lopez, 2017, for reviews). For instance, satisfaction of the autonomy need was found to be positively related to intrinsic motivation (e.g., Hagger, Sultan, Hardcastle, & Chatzisarantis, 2015; Mouratidis, Michou, Aelterman, Haerens, & Vansteenkiste, 2018; Vansteenkiste et al., 2012; Vasquez, Patall, Fong, Corrigan, & Pine, 2016), academic motivation (e.g., Chirkov & Ryan, 2001; Ricard & Pelletier, 2016), behavioral, cognitive, and emotional engagement (e.g., Hospel & Galand, 2016; Reeve, Jang, Carrell, Jeon, & Barch, 2004; Ruzek et al., 2016; Vasquez et al., 2016), self-regulated learning (e.g., Schuitema, Peetsma, & van der Veen, 2016; Vansteenkiste et al., 2012), perceived cognitive competence (e.g., Ryan & Grolnick, 1986), and academic achievement (e.g., Diseth & Samdal, 2014; Vasquez et al., 2016). Similarly, satisfaction of the competence need was also found to be positively linked to intrinsic motivation (e.g., Jang, Reeve, Ryan, & Kim, 2009; Sheldon & Filak, 2008), affect (e.g., Veronneau, Koestner, & Abela, 2005a, 2005b), engagement (e.g., Jang, Kim, & Reeve, 2016), and academic achievement (e.g., Froiland & Worrell, 2017).

Nonetheless, only a small body of research has examined the relations of autonomy and competence with science-related dispositions and outcomes among school children. For example, Jungert and Koestner (2015) explored whether or not autonomy support from science teachers and parents would enhance autonomous motivation, self-efficacy, and science achievement of high school students in science programs. They found that autonomy support from science teachers was significantly positively related to students' autonomous motivation, self-efficacy, and science achievement. Recently, Patall, Hooper, Vasquez, Pituch, and Steingut (2018), employing a daily diary approach, investigated the relationship between perceived teacher autonomy support and perceived competence in science among high school students. The authors found that the decrease in perceived competence in science as a function of perceived difficulty was reduced when the students perceived their teachers as supporting their autonomy during science classes. Given the numerous beneficial academic outcomes of autonomy and competence in school children, it is paramount to investigate the relations of perceived competence in ICT usage and perceived autonomy related to ICT usage to the enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science. Hence, based on self-determination theory's propositions, the following two research questions were addressed in the study:

RQ1: How well does perceived competence in ICT usage predict enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science, after accounting for student-, school-, and country-level demographic characteristics?

RQ2: How well does perceived autonomy related to ICT usage predict enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science, after accounting for student-, school-, and country-level demographic characteristics?

3. Method

3.1. Data

The data for the study were drawn from the Organization for Economic Cooperation and Development's (OECD) Program for International Student Assessment (PISA) 2015 database (http://www.oecd.org/pisa/data/2015database). PISA, a triennial international survey, assesses the knowledge and life skills of 15-year-old students in participating countries. The PISA assessments include science, mathematics, reading, collaborative problem solving, and financial literacy components (OECD, 2017). The focus of PISA 2015 was on science literacy. Over half a million 15-year-old students from 18,599 schools in 72 countries and economies took part in the PISA 2015 assessments and surveys (OECD, 2017). In addition, school principals of participating schools also completed a school questionnaire. The present study is based on the PISA 2015 student questionnaire, ICT familiarity questionnaire for students (optional for participating countries), and school questionnaire data. The country-level data were drawn from the World Bank database (https://data.worldbank.org/indicator) and the Central Intelligence Agency (CIA) world factbook (https://www.cia.gov/library/publications/the-world-factbook). Of the 72 PISA 2015 participating countries and economies, 42 countries chose to administer the optional ICT familiarity component for the student questionnaire. The ICT familiarity questionnaire asked students about different aspects related to digital media and digital devices, including computers (e.g., desktop computer, portable laptop, or notebook), tablet computers (e.g., iPad, BlackBerry, PlayBook), Internet, cell phones with Internet access (e.g., smartphones), cell phones without Internet access, video game consoles (e.g., Sony PlayStation), e-book readers (e.g., Kindle, Kobo, Bookeen), and Internet-connected television. The sample of the current study comprised 258,192 15-year-olds (male = 127,469 (49%), female = 130,723 (51%); M_{age} = 15.79 years, SD = 0.29) from 10,767 schools in 42 countries. The list of countries and subnational entities included in the study is given in Appendix A.

3.2. Measures

3.2.1. Students' perceived ICT competence

Students' perceived competence in ICT usage was measured using the following five items: "I feel comfortable using digital devices that I am less familiar with"; "If my friends and relatives want to buy new digital devices or applications, I can give them advice"; "I feel comfortable using my digital devices at home"; "When I come across problems with digital devices, I think I can solve them"; and "If my friends and relatives have a problem with digital devices, I can help them" (OECD, 2017). All five items were rated on a four-point Likert-type scale, ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). The internal consistency reliability of the scale (i.e., Cronbach's α) across the national samples ranged from 0.77 to 0.89.

3.2.2. Students' perceived autonomy related to ICT use

Students' perceived autonomy related to ICT usage was assessed using the following five items: "If I need new software, I install it by myself"; "I read information about digital devices to be independent"; "I use digital devices as I want to use them"; "If I have a problem with digital devices, I start to solve it on my own"; and "If I need a new application, I choose it by myself" (OECD, 2017). All items were rated on a four-point Likert-type scale, ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). The internal consistency reliability of the scale across the national samples ranged from 0.80 to 0.91.

3.2.3. Enjoyment of science

Students' enjoyment of science was measured using the following five items: "I generally have fun when I am learning broad science topics.“; "I like reading about broad science"; "I am happy working on broad science topics"; "I enjoy acquiring new knowledge in broad science"; and "I am interested in learning about broad science" (OECD, 2017). All five items were rated on a four-point Likert-type scale, ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). The internal consistency reliability of the scale across the national samples ranged from 0.90 to 0.97.

3.2.4. Interest in broad science topics

Students' interest in broad science topics, such as the biosphere, motion and forces, energy and its transformation, the Universe and its history, and how science can help prevent disease, was rated on a four-point Likert-type scale, ranging from 1 (*not interested*) to 4 (*highly interested*) (OECD, 2017). The internal consistency reliability of the scale across the national samples ranged from 0.71 to 0.89.

3.2.5. Science self-efficacy

To assess students' science self-efficacy, they were asked to rate how well they thought they could perform the following eight scientific tasks: recognize the science question that underlies a newspaper report on a health issue; explain why earthquakes occur more frequently in some areas than in others; describe the role of antibiotics in the treatment of disease; identify the science question associated with the disposal of garbage; predict how changes to an environment will affect the survival of certain species; interpret the scientific information provided on the labelling of food items; discuss how new evidence can lead you to change your understanding about the possibility of life on Mars; and identify the better of two explanations for the formation of acid rain (OECD, 2017). All eight items were rated on a four-point Likert-type scale, ranging from 1 (*I couldn't do this*) to 4 (*I could do this easily*). The internal consistency reliability of the scale across the national samples ranged from 0.83 to 0.94.

3.2.6. Epistemological beliefs

Students' epistemological beliefs about science were measured using the following six items: a good way to know if something is true is to do an experiment; ideas in broad science sometimes change; good answers are based on evidence from many different experiments; it is good to try experiments more than once to make sure of your findings; sometimes broad science scientists change their minds about what is true in science; and the ideas in broad science books sometimes change (OECD, 2017). All six items were rated on a four-point Likert-type scale, ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). The internal consistency reliability of the scale across the national samples ranged from 0.80 to 0.94.

3.2.7. Student-, school-, and country-level control variables

The following student-, school-, and country-level variables and measures were used as covariates in the study: gender (0 = male, 1 = female), immigration status (0 = immigrant [n = 24,404], 1 = non-immigrant [n = 233,788]), the PISA 2015 index of economic, social and cultural status (ESCS; a composite score of highest level of education of parents, highest parental occupational status, and home possessions; see OECD, 2017), school-mean ESCS, school ownership type (0 = private [n = 2175], 1 = public [n = 8592]), income GINI coefficient (CIA, 2017; World Bank, 2017), and log GDP per capita (CIA, 2017; World Bank, 2017). The OECD constructed all student- and school-level measures used in the study employing one of the modern test theory techniques, item response theory (IRT; see OECD, 2017).

3.2.8. Analytic strategy

Prior to the main analyses, preliminary analyses were conducted to screen the data for univariate and multivariate normality, homoscedasticity, and multicollinearity. Values of univariate skewness and kurtosis of $< \pm 2.00$ were considered indicative of univariate normality, whereas value of Mardia's normalized multivariate kurtosis of $< \pm 3.00$ was considered indicative of multivariate normality (Bandalos, 2018). To test for homoscedasticity, we plotted scatterplots of the standardized residuals and the standardized predicted scores. Homoscedasticity was assumed "if the residuals were evenly distributed around zero throughout the entire length of the scatterplots" (Kline, 2009, p. 247). We checked for multicollinearity using tolerance and the variance inflation factor (VIF) values. Tolerance values < 0.10 and VIF values > 10.00 were considered indicative of multicollinearity (Cohen, Cohen, West, & Aiken, 2003; DeMaris, 2004).

To answer the two research questions, multilevel structural equation modeling (MSEM; see Hox, 2013; Mehta & Neale, 2005) analyses were conducted using M*plus* Version 8.1 (Muthén & Muthén, 1998-2018). MSEM not only combines the best of both structural equation modeling (SEM) and multilevel modeling (MLM), but also takes into account the measurement error (Hox, 2013; Mehta & Neale, 2005). The hypothesized multilevel structural equation model is shown in Fig. 1. The student-level exogenous variables and measures in the multilevel structural model were gender, immigration status, ESCS, perceived ICT competence, and perceived autonomy related to ICT use. The school-level exogenous variables in the multilevel structural equation model were school ownership type and school-mean ESCS. The country-level exogenous variables in the multilevel structural equation model were the income Gini coefficient and the log GDP per capita. The endogenous measures in the multilevel structural equation model were the enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs.

Because grand mean centering helps to reduce multicollinearity (see Tabachnik & Fidell, 2013), all student-, school-, and country-level continuous exogenous measures were grand mean centered (see Brincks et al., 2017). All dichotomous variables were kept in their original metric. The multilevel structural equation model was estimated using the maximum likelihood with robust standard errors (MLR) estimation procedure. The MLR estimation procedure is capable of effectively addressing nonnormality, unbalanced group sample sizes, and model complexity (see Maydeu-Olivares, 2017). The PISA 2015 sampling weights, both student- and school-level sample weights, were incorporated into the multilevel structural equation model to produce unbiased estimates of standard errors (see Asparouhov, 2006; OECD, 2017). The percentage of missing values for the variables of interest in the study ranged from 0.1% to 15.3%. The full information maximum likelihood (FIML) method, implemented in the M*plus* program, was used to handle the missing data (see Enders, 2001; Enders & Bandalos, 2001). The fit of the hypothesized multilevel structural equation model was assessed using the following goodness-of-fit indices (Schreiber, Nora, Stage, Barlow, & King, 2006): root mean square error of approximation (RMSEA < 0.08), standardized root mean square residual (SRMR ≤ 0.08), comparative fit index (CFI ≥ 0.95), and Tucker-Lewis index (TLI ≥ 0.95).

4. Results

The results of the preliminary analyses indicated that values of univariate skewness and kurtosis were $< \pm 2.00$ for the main variables of interest in the study, suggesting that the univariate normality assumption is not violated. However, the value of Mardia's normalized multivariate kurtosis was > 3.00, indicating possible departures from multivariate normality. Hence, cases identified as multivariate outliers were excluded from subsequent analyses. An examination of the scatterplots revealed that the standardized residuals were evenly distributed around zero, suggesting homoscedasticity of the variances. Moreover, tests for multicollinearity indicated that tolerance and VIF values were > 0.10 and < 10.00, respectively, indicating the absence of multicollinearity.

The descriptive statistics for all variables and measures used in the multilevel structural equation model are given in Table 1. All PISA 2015 IRT scales have a mean of 0 and a standard deviation of 1 across OECD-member countries (OECD, 2017). Hence, negative mean scale scores indicate that students responded less positively than the average student across OECD-member countries, whereas positive mean scale scores suggest that students responded more positively than the average student in OECD-member countries (OECD, 2017). The intercorrelations among the latent measures are given in Table 2. Both perceived ICT competence and perceived autonomy related to ICT use were more strongly and positively correlated with epistemological beliefs about science and science self-efficacy, followed by interest in broad science topics and enjoyment of science (see Table 2).

The hypothesized multilevel structural equation model fitted the data well, CFI = 1.000, TLI = 1.000, RMSEA = 0.000, $SRMR_{within} = 0.000$, $SRMR_{between\ level\ 2} = 0.001$, and $SRMR_{between\ level\ 3} = 0.000$. The intraclass correlation coefficients (ICCs; see Table 3) indicated that 4%, 3%, 3%, and 4% of the variances in enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs, respectively, were at the school-level (i.e., between-school variance), and 7%, 9%, 4%, and 3% of the variances in enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs, respectively, were at the country-level (i.e., between country variance).

Results of MSEM analyses (see Fig. 2) revealed that students' perceived ICT competence was statistically significantly positively associated with their enjoyment of science (b = 0.04, SE = 0.01, $p < 0.001$), interest in broad science topics (b = 0.03, SE = 0.01, $p < 0.001$), science self-efficacy (b = 0.06, SE = 0.01, $p < 0.001$), and epistemological beliefs (b = 0.08, SE = 0.01, $p < 0.001$). Students who reported higher levels of perceived ICT competence tended to report higher levels of enjoyment of science, interest in broad science

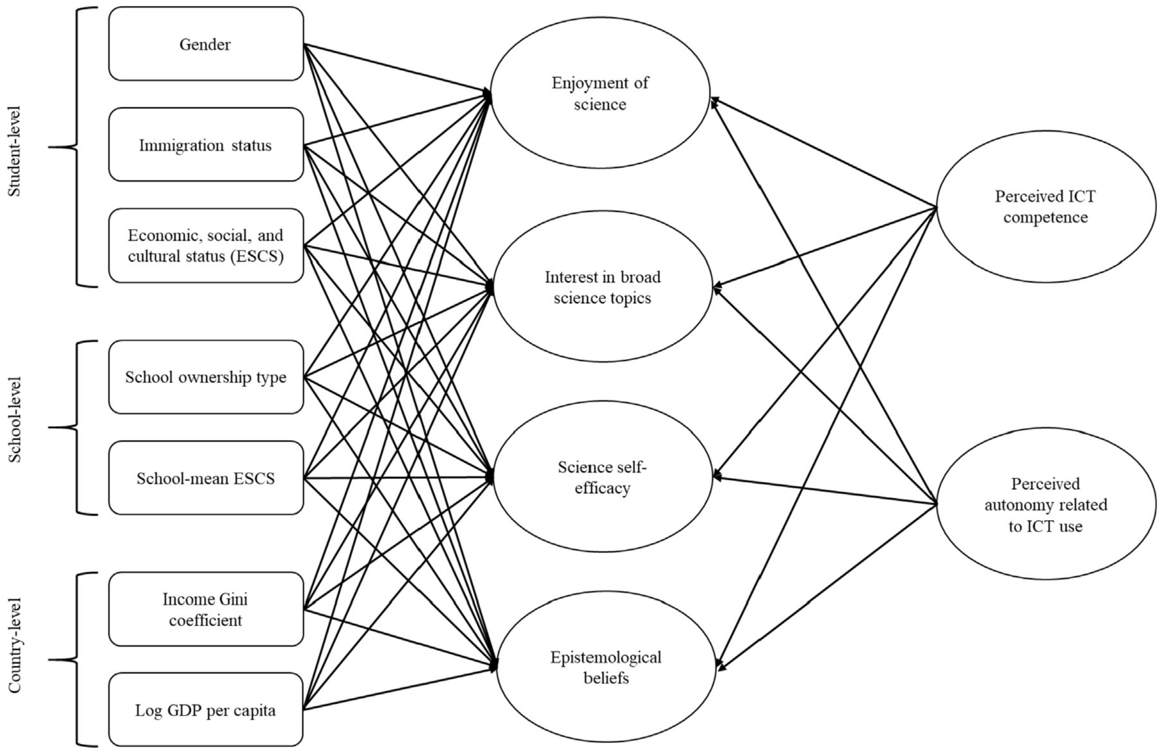

Fig. 1. The hypothesized multilevel structural equation model.

Table 1
Descriptive statistics for variables and measures.

Variables/measures	*M*	*SD*
Student-level		
Gender	0.50	0.50
Immigration status	0.89	0.25
Economic, social, and cultural status (ESCS)	−0.25	0.94
Perceived ICT competence	−0.02	0.95
Perceived autonomy related to ICT use	−0.01	0.98
Enjoyment of science	0.08	1.06
Interest in broad science topics	0.09	0.94
Science self-efficacy	0.04	1.22
Epistemological beliefs	−0.03	0.96
School-level		
School mean ESCS	−0.30	0.74
School ownership type	0.80	0.40
Country-level		
Income Gini coefficient	0.36	0.08
Log GDP per capita	10.09	0.76

Table 2
Correlations among the latent measures.

	1	2	3	4	5	6
1. Perceived ICT competence	–					
2. Perceived autonomy related to ICT use	0.63					
3. Enjoyment of science	0.11	0.13				
4. Interest in broad science topics	0.11	0.13	0.54			
5. Science self-efficacy	0.13	0.15	0.33	0.30		
6. Epistemological beliefs	0.16	0.18	0.33	0.26	0.19	–

Note. All correlations are significant at $p < 0.001$.

topics, science self-efficacy, and epistemological beliefs than did their peers who reported lower levels of perceived ICT competence.

Similarly, students' perceived autonomy related to ICT use was also statistically significantly positively related to their enjoyment of science ($b = 0.09$, $SE = 0.01$, $p < 0.001$), interest in broad science topics

Table 3
Estimated intraclass correlation coefficients (ICC) for the endogenous measures.

	School-level	Country-level
Enjoyment of science	0.04	0.07
Interest in broad science topics	0.03	0.09
Science self-efficacy	0.03	0.04
Epistemological beliefs	0.04	0.03

($b = 0.06$, $SE = 0.01$, $p < 0.001$), science self-efficacy ($b = 0.11$, $SE = 0.01$, $p < 0.001$), and epistemological beliefs ($b = 0.12$, $SE = 0.01$, $p < 0.001$). Students who reported higher levels of perceived autonomy related to ICT use also tended to report higher levels of enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs than did their counterparts who reported lower levels of perceived autonomy related to ICT use. The standardized coefficients suggested that students' perceived autonomy related to ICT use was more strongly associated with dispositions toward science than their perceived ICT competence: enjoyment of science ($\beta = 0.08$, 0.04, respectively), interest in broad science topics ($\beta = 0.07$, 0.03), science self-efficacy ($\beta = 0.09$, 0.05), and epistemological beliefs ($\beta = 0.13$, 0.08). The estimated student-, school-, and country-level variance components are given in Table 4.

5. Discussion

The present study investigated the associations of ICT-related dispositions (i.e., perceived competence in ICT usage and perceived autonomy related to ICT usage) with science-related dispositions (i.e., enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science) among 15-year-old students who took part in the PISA 2015 assessments and surveys. Results of the study, congruent with the propositions of self-determination theory (see Ryan & Deci, 2017), indicated that both perceived competence in ICT usage and perceived autonomy related to ICT usage were significantly positively associated with enjoyment of science,

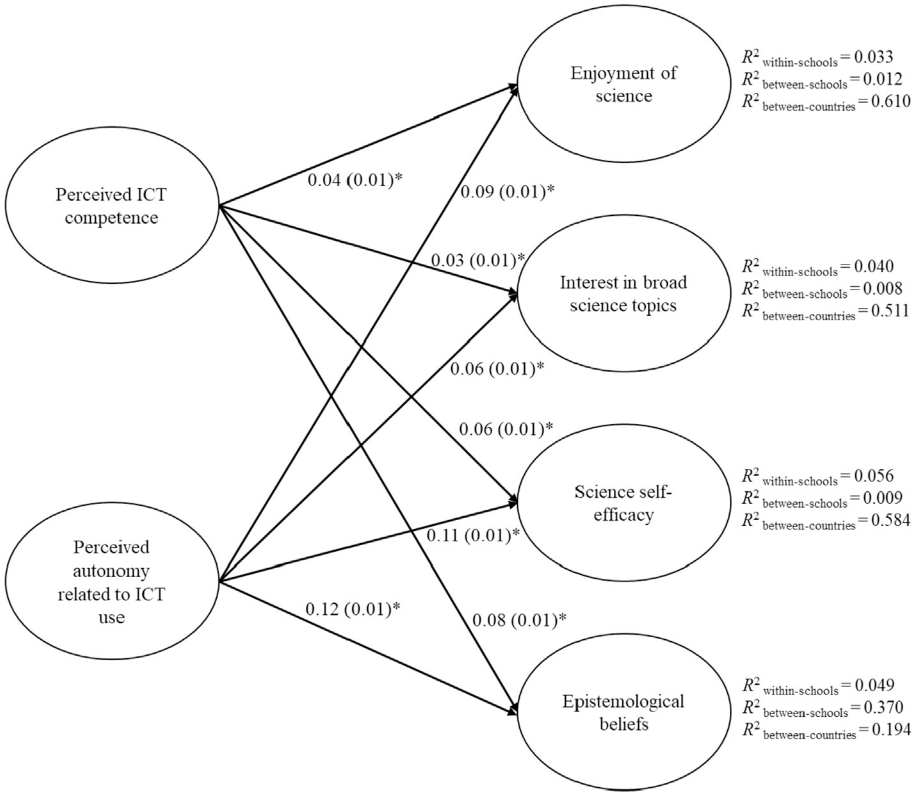

Fig. 2. Results of multilevel structural equation modeling analyses. Standard errors are in parentheses. All student-, school-, and country-level control variables were included in the analyses; but for clarity of presentation purposes, only the main measures of interest are shown. $^*p < 0.001$.

Table 4
Estimated variance components.

Parameter	Estimate	*SE*	*p*
Student-level			
Enjoyment of science	1.047	0.03	0.000
Interest in broad science topics	0.807	0.02	0.000
Science self-efficacy	1.385	0.03	0.000
Epistemological beliefs	0.842	0.02	0.000
School-level			
Enjoyment of science	0.046	0.01	0.000
Interest in broad science topics	0.029	0.00	0.000
Science self-efficacy	0.040	0.00	0.000
Epistemological beliefs	0.024	0.00	0.000
Country-level			
Enjoyment of science	0.034	0.01	0.000
Interest in broad science topics	0.040	0.01	0.000
Science self-efficacy	0.024	0.00	0.000
Epistemological beliefs	0.025	0.00	0.000

interest in broad science topics, science self-efficacy, and epistemological beliefs about science among these adolescent students hailing from 42 countries across the world. Furthermore, results of the study suggested that perceived autonomy related to ICT usage was a stronger predictor of enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science than perceived competence in ICT usage.

In recent decades, there has been a steady growth in the use of ICTs to support science learning in schools and at home (see Kelleher, 2000; Law, Pelgrum, & Plomp, 2008). Both school- and home-based use of ICTs provide students a range of affordances for learning science with ICTs (see Cox & Webb, 2004; Webb, 2005; Wellington & Britto, 2004). Affordances of ICT-rich school and home learning environments may provide students ample opportunities conducive to supporting and enhancing their perceived competence in ICT usage and perceived autonomy related to ICT usage, which, in turn, may help them develop positive dispositions toward science (see Park, Khan, & Petrina, 2009). Given the significant positive relations of ICT-related dispositions to science-related dispositions, it is essential to explore the implications of these findings for classroom teachers, school principals/administrators, parents, and policymakers.

5.1. Implications for policy and practice

Satisfaction of the ICT-related competence and autonomy needs is critical for improving students' enjoyment of science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science. Autonomy-supportive teachers can play a crucial role in the satisfaction of their students' ICT-related competence and autonomy needs. Autonomy-supportive instruction primarily includes the following instructional behaviors: "nurture inner motivational resources; provide explanatory rationales; rely on non-controlling and informational language; display patience to allow time for self-paced learning; and acknowledge and accept expressions of negative affect" (Reeve, 2009, p. 160). However, most teachers across the world do not tend to adopt an autonomy-supportive motivating style toward their students during classroom instruction (see Areepattamannil, Freeman, & Klinger, 2018; Reeve, 2009; Reeve et al., 2014). Yet, there is that carefully designed and theory-based autonomy-supportive interventions may help controlling teachers to become more autonomy-supportive toward their students (see Su & Reeve, 2011). Recently, Cheon, Reeve, Lee, and Lee (2018) demonstrated that a workshop-oriented autonomy-supportive intervention program was effective in transforming teachers' controlling motivating style into a more autonomy-supportive motivating style. The authors documented that intervention-enabled gains in teaching efficacy and intrinsic instructional goals increased teachers' autonomy-supportive motivating style.

Nevertheless, well-designed and theory-ridden autonomy-supportive intervention programs may not alone help teachers to become more autonomy-supportive toward their students. Several reasons may force teachers to adopt a controlling motivating style toward their students rather than an autonomy-supportive motivating style (Pelletier, Séguin-Lévesque, & Legault, 2002; Reeve, 2009). For example, pressures from above (e.g., school administrators/principals), pressures from below (e.g., students), and pressures from within may demotivate teachers to adopt an autonomy-supportive motivating style toward their students (Pelletier et al., 2002; Reeve, 2009). Hence, school administrators/principals may need to create a supportive and positive school environment that helps to enhance teachers' autonomy motivating style toward students.

To develop and promote students' ICT-related competence and autonomy, teachers' support of autonomy might not alone suffice. Autonomy-supportive parenting can also play a significant role in the satisfaction of students' basic psychological needs for competence and autonomy (see Costa, Gugliandolo, Barberis, Cuzzocrea, & Liga, 2018; Soenens et al., 2007; van der Kaap-Deeder et al., 2015). A considerable body of research has documented the beneficial outcomes of autonomy-supportive parenting in the realms of education and psychology, such as academic achievement (e.g., Liew, Kwok, Chang, Chang, & Yeh, 2014), academic motivation (e.g., Chirkov & Ryan, 2001), executive function (e.g., Distefano, Galinsky, McClelland, Zelazo, & Carlson, 2018), adolescent autonomy (e.g., Fousiani, Van Petegem, Soenens, Vansteenkiste, & Chen, 2014), and psychological well-being (e.g., Vasquez et al., 2016). Well-thought-out autonomy-supportive parenting intervention programs may help parents to adopt an autonomy-supportive motivating style toward their children (Joussemet, Landry, & Koestner, 2008). Finally, at the policy level, reforms aimed at improving the quality of pre-service teacher education programs may need to ensure that the pre-service teacher education curriculum includes adequate provisions for developing future teachers' repertoire of autonomy-supportive instructional behaviors, strategies, and skills.

In addition to creating an autonomy-supportive climate, other pertinent steps at the school- and country-levels may also need to be taken to enhance students' ICT-related competence and autonomy. Schools across countries, besides ensuring access to ICTs, may require to incorporate ICTs into the school curriculum. An ICT integrated school curriculum may provide students ample opportunities to master ICT skills. There is growing evidence that access to and use of ICTs play crucial roles in developing students' ICT competence (e.g., Areepattamannil & Khine, 2017; Rohatgi et al., 2016; Warschauer & Matuchniak, 2010; Zhong, 2011). However, students' access to and use of ICTs may not alone develop their ICT competencies. Schools may need to take appropriate measures to promote ICT professional development for teachers. Integrating ICT training into teachers' professional development might be an important step forward toward the realization of this goal. Such ICT integrated professional development programs may empower teachers to develop high-quality instructional materials that are helpful in promoting students' ICT competence and autonomy. Furthermore, school policies aimed at building partnerships with ICT giants, such as Microsoft, Google, and Apple, may also provide students enormous opportunities for accessing and using cutting-edge technologies. Holding intra- and inter-school ICT-related competitions might also help develop students' ICT-related competence and autonomy. At the country-level, concerted efforts to increase the ICT penetration level may be needed to boost students' ICT-related competence and autonomy. Country-specific sustainable policies targeted at narrowing the digital divide may go a long way toward raising the ICT penetration level.

5.2. Limitations and directions for future research

The study has three major limitations. First, the instruments used in the study were self-report instruments. Although self-report instruments have been widely used by psychologists and educators for decades, the use of such instruments in social and behavioral science research has been criticized on grounds of response bias factors, such as acquiescence (i.e., the tendency to endorse items positively regardless of content; Kline, 1986) and social desirability (i.e., the tendency to endorse items in accord with the social desirability of the response; Kline, 1986). Future research examining relationships between the measures of interest in the present study may need to employ more sophisticated alternatives to self-report measures, such as behavioral, physiological, or implicit measures. Second, the study was cross-sectional in nature. Hence, causality cannot be assumed. Further research using longitudinal and experimental research designs is required to investigate potential causal relationships between ICT-related dispositions and science-related dispositions. Finally, the countries included in the study vary hugely in terms of their social, economic, cultural, political, and religious characteristics. All potential country-level confounding factors were not accounted for in the current study. Therefore, more country-specific research is warranted to establish the cross-cultural generalizability of the hypothesized model in the study.

6. Conclusion

Notwithstanding these limitations, grounded in self-determination theory's propositions, this study provided empirical support for the positive associations of perceived competence in ICT usage and perceived autonomy related to ICT usage with enjoyment in science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science among nationally representative samples of 15-year-old students in 42 countries. The findings of the study also revealed that perceived autonomy related to ICT usage was more strongly associated with enjoyment in science, interest in broad science topics, science self-efficacy, and epistemological beliefs about science than perceived competence in ICT usage. Well-designed, sound theory-based, and empirically tested autonomy-supportive intervention programs may be needed to satisfy adolescent students' ICT-related competence and autonomy needs. Given the positive links between ICT-related dispositions and science-related dispositions, future research may be required to examine the mediating effects of science-related dispositions on the relationships between ICT-related dispositions and science achievement.

Appendix A. Countries/subnational entities included in the study

Australia	Germany	Peru
Austria	Greece	Poland
Belgium	Hong Kong	Portugal
Brazil	Hungary	Russian Federation
Bulgaria	Iceland	Singapore
Chile	Ireland	Slovak Republic
Chinese Taipei	Italy	New Zealand
Colombia	Japan	Slovenia
Costa Rica	Korea	Spain
Croatia	Latvia	Switzerland
Czech Republic	Lithuania	Thailand
Denmark	Luxembourg	United Kingdom

Dominican Republic	Macao	Uruguay
Estonia	Mexico	Beijing-Shanghai-Jiangsu-Guangdong (China)
Finland	Netherlands	Spain (Regions)
France		

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