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The Importance of Arts-related Information and Communication Technology (ICT) Use in Problem Solving and Achievement

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Objectives

With increasingly popular applications of ICT in the creative arts, particularly in visual graphics and music (Crow, 2006; Webster, 2007), a growing body of research has now centered on understanding how the integration of ICT in arts activities may bring about improvements in students' cognitive functioning and academic attainments (e.g., Gadanidis et al., 2011). To contribute to this emerging body of research, the present study seeks to investigate the extent to which students' use of ICT for arts-related purposes is associated with their problem-solving skill and science and mathematics achievement. Based on analyses of the Programme for International Student Assessment (PISA) 2003 database comprising a specialist focus on students' problem-solving skill (OECD, 2004a, 2004b), the study examines the potential role that problem-solving skill plays in mediating the relationships between arts-related ICT use and science and mathematics achievement (Figure 1). Importantly, consistent with concerns encapsulated in recent arguments about the digital divide (Attewell et al., 2003), we disentangle the *quality* from the *quantity* of arts-related ICT use, with the former defined as students' perceived capacity or efficacy in using ICT for arts-related purposes including drawing digital graphics, creating multimedia presentations, downloading music from the Internet, and the latter as the amount or frequency of student engagement in ICT for such arts-related purposes.[1]

Perspectives and Theoretical Framework

[1]Consistent with the recent operational definition by the National Endowment for the Arts (NEA, 2009), arts participation encompasses various activities relevant to art, dance, drama, film/media and music involving active (e.g., playing a musical instrument, singing in a concert) or receptive (e.g., visiting the art gallery, attending a concert) engagement, including that involving ICT (e.g., downloading and listening to recorded music, watching drama or dance performance online).

In largely independent bodies of research, the roles of arts participation and of ICT use in students' cognitive and/or academic functioning have been encapsulated in different theoretical-conceptual models. In terms of the relationships between arts participation and academic outcomes, the *developmental* (Marsh & Kleitman, 2002) and *leisure* (Caldwell & Witt, 2011) models propose that, as a form of constructive leisure activity, arts participation fosters students' holistic development. This perspective views students' enhanced academic performance as a result of the development of their psychosocial capitals, such as heightened general self-esteem and life satisfaction, with which arts participation has been associated. Of particular relevance to the present study is the *transfer of learning* model (Aprill, 2001; Burton, Horowitz, & Abeles, 1999) which maintains that arts participation contributes to the development of higher-order cognitive skills crucial to the process of academic learning. While evidence supporting this model is still relatively inconclusive, recent experimental studies commissioned by New York's Guggenheim Museum (Randi Korn & Associates [RK&A], 2007, 2010) showed that arts engagement is associated with creative and flexible thinking, reasoning, and information seeking capacities.

The importance of ICT in students' cognitive and academic outcomes has been predominantly studied in the contexts of computer-assisted instruction (CAI). Meta-analyses have shown that CAI is associated with effective learning and improved achievement in mathematics (Li & Ma, 2011) and science (Liao, 2007). The positive effects of CAI on academic performance has been attributed to the enhanced motivation that students gain when learning with ICT as students are provided with chances to learn within an interactive and dynamic atmosphere (Gadanidis et al., 2011). From a constructivist perspective (e.g., McCombs, 2000), the cognitive benefits of CAI are believed to be associated with the benefits of instructional practices underpinned by constructivist principles seeking to encourage learners to be active constructors of their own knowledge through the engagement with relevant tasks, immediate feedback, and structured guidance – all these are directly emphasized in CAI.

The Potentially Mediating Role of Problem-Solving Skill

Consistent with the transfer of learning perspective (Aprill, 2001), a potential psychological process through which students' arts-related ICT use may impact achievement is through the mediation of problem-solving skill fostered during students' engagement in arts-related use of ICT. Indeed, on the one side, the literature has established the benefits of arts engagement for problem solving and critical thinking (RK&A, 2007, 2010) and the generally adaptive impact of ICT use and ICT-based instruction on the cognitive development (Attewell et al., 2003; Hew & Brush, 2007). On the other side, problem solving has been proposed as a core process of doing and excelling in mathematics and science (Mayer, 2008; Toh, Quek, & Leong, 2011). Indeed, efforts to improve mathematics and science achievement are now directed at developing students' problem- solving skill and empower them to apply the associated cognitive functioning and meta-strategic knowledge to solve mathematical and scientific problems (U.S. National Council of Teachers of Mathematics [NCTM], 1989; U. S. National Research Council [NRC], 1996).

Method

Data Source and Sample

The sample comprised 197,024 students drawn from the PISA 2003 database which to date was the only available PISA database containing problem-solving skill as one of its assessment foci. Female and male students were approximately equally represented. The participants' ages ranged between 15.17 and 16.42 years (*M* = 15.80, *SD* = 0.29). About 3.6% of the students spoke a language at home other than the test language (non-test speaking background or NTSB). Students involved in the present analyses were drawn from the 25 OECD countries that administered the ICT survey to their students (OECD, 2005).

Materials

The quantity of ICT use for *arts-related purposes* was based on students' responses to the two items that most pertained to the arts as broadly defined by National Endowment for the Arts (2009) (i.e., 'How often do you use drawing, painting or graphics programs on a computer?' and 'How often do you use the Internet to download music?'). These items were rated on a 5-point response scale ranging from "almost every day" (scored 1) to "never" (5), which were reverse-coded in the present analysis such that higher scores reflect higher frequencies of arts-related ICT use. Students' reported competence at using the ICT for arts-related purposes was measured by three indicators: creating a multi-media presentation with sound, pictures, and video; drawing pictures using a mouse; and downloading music from the Internet. Students rated these items on a 4-point response scale ranging from "I can do this very well by myself" (scored 1) to "I don't know what this means" (4), which were reverse-coded in the present analysis such that higher scores represent higher confidence at arts-related ICT use.

The PISA assessment of problem solving seeks to measure students' problem-solving competencies beyond the boundaries of formal curricular areas. Accordingly, the problem solving factor assessed is "an amalgam of many different cognitive processes that are orchestrated to achieve a certain goal that could not be reached, at least obviously, by simply applying a well-known procedure, process, routine or algorithm from a single subject area" (OECD, 2003, p. 159). The three formats of problem solving items were multiple choice, closed-constructed response, and open-constructed response and these items can be categorized into three units: decision making, system analysis and design, and trouble shooting.

As reported in OECD (2004a), students' mathematics knowledge and skills were assessed by 85 items categorized into four overarching domains: quantity (23 items), space, distance, and shape (20 items), change and relationships (22 items), and uncertainty (20 items). About 50% of the items required students to construct their own answers (open-ended items), around 15% of the items were closed-ended response items, and the remaining items were in a multiple-choice format. Students' science knowledge and skills were assessed by 35 items divided into three areas: earth and environment (12 items), life and health (12 items), and technology (11 items). Around 43% of the items required students to construct their own answers and 57% of the items were in a multiple-choice format.

Analyses

The mediation model was assessed using structural equation modeling (SEM) performed using Mplus 6.0 (Muthén & Muthén, 2012). Goodness of fit was established via the Comparative Fit Index (CFI), the Non-Normed Fit Index (NNFI), the Root Mean Square Error of Approximation (RMSEA), and the χ^2 test statistic. Maximum likelihood with robustness to non-normality and non-independence of observations (MLR) was used for estimation.

Results

Preliminary Measurement and Correlational Analyses

Confirmatory factor analysis (CFA) was first conducted to assess the factor structure of the central latent factors in the study. The analysis showed an excellent fit of the data to the model, χ^2=(df=558, N=197,024)=190,223.20, p<.001, CFI=.98, NNFI=.98, and RMSEA=.04. All factor loadings were significant at p<.001, with the mean factor loading of .70. These results indicate that the latent factors under study are sound and provide a robust measurement basis upon which to the modeling aimed at addressing the key substantive questions. Table 1 presents correlations amongst latent factors resulted from the preliminary CFA.

Central Analyses

The SEM showed that the proposed model fit the data well, χ^2=(df=521, N=197,024)= 95,126.73, p<.001, CFI=.98, NNFI=.98, and RMSEA=.03. Figure 2 graphically depicts the findings. The results showed that problem-solving skill positively predicted both science and mathematics achievement; however, its effect on mathematics achievement was higher than on science achievement. The results also showed that whilst problem-solving skill fully mediated the effects of arts-related ICT use on mathematics achievement, it partially mediated the corresponding effects on science achievement. As shown in Table 2, for the most part, the key predictive paths in the whole-sample model generalized across individual countries.

The significant effect of the quality x quantity interaction on problem-solving skill was graphically interpreted. As reflected in a steeper slope in Figure 3, the negative effect of quantity of arts-related ICT use on problem-solving skill was stronger for students who reported lower quality ICT use (β=-.22, p<.001) than for those with moderate or high quality ICT use (β=-.12 and β=-.09, respectively, p<.001). As shown in Table 3, students with different quantity of ICT use did not substantially differ in their problem-solving skill when they experienced moderate or high quality ICT use. This finding underscores the importance of fostering high quality ICT use to mitigate any negative effects of high quantity ICT use.

Scientific and Scholarly Significance

The results illustrate and highlight the need to monitor the quantity and quality of students' engagement in ICT for arts-related purposes and the role of problem-solving skill in mediating the predictive relationships between arts-related ICT use and mathematics and science achievement. The significant effect of quantity x quality of arts-related ICT use suggests the importance of considering students' efficacy in the use of ICT for arts-related purposes especially in cases where students may spend larger amounts of time in ICT use. This finding supports a recent engagement perspective (Bohnert, Fredricks, & Randall, 2010) claiming that, "merely attending an activity may not be sufficient for reaping the benefits of involvement" (p. 593). That is, whilst students can be physically present at an activity, they may not be qualitatively connected to or effectively engaged in the activity. Hence, in addition to the frequency of engagement widely used as an indicator of youth involvement in an activity, the present study has included, and shown the importance of considering, the quality of the engagement in seeking to understand the role of arts-related ICT use in cognitive development.

Consistent with the transfer of learning model (e.g., Aprill, 2001), arts activities would first promote students' development of cognitive skills which then brings about positive changes in their academic performance. Similarly, educational technologists have suggested that the use of ICT may not directly impact academic performance but be mediated by the cognitive skills developed through students' interaction with technology (McFarlane & Sakellariou, 2002; Subrahmanyam et al., 2000). The study provides some empirical support to this speculation by suggesting the cognitive mechanism through which arts-related use of technology may benefit academic development. From learning and instruction perspectives, this finding implies that pedagogies aimed at improving students' science and mathematics performance can be enhanced through greater emphasis on the development of learners' competence in problem-solving transfer (Mayer & Wittrock, 1996). This would involve equipping students with key cognitive skills associated with problem-solving and teaching them how to use these skills to solve mathematical and scientific problems (NCTM, 1989; NRC, 1996).

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Table 1

Latent Factor Correlations of Key Factors in the Model

		1	2	3	4	5	6	7	8	9	10	11	12
1.	Gender	-											
2.	Age	.01	-										
3.	Language background	.01	.01	-									
4.	Parent Education	.03	.01	-.01	-								
5.	Home Educational Res.	-.04	.03	-.01	.38	-							
6.	Home Computer Res.	.04	.02	.06	.48	.57	-						
7.	Home Cultural Res.	-.09	-.01	-.04	.38	.61	.37	-					
8.	Quality of ICT Use	.19	.02	.07	.25	.23	.51	.18	-				
9.	Quantity of ICT Use	.19	.02	.08	.18	.11	.44	.10	.50	-			
10.	Problem Solving	.01	.07	-.03	.43	.49	.55	.38	.25	.05	-		
11.	Science	.04	.07	-.07	.39	.46	.48	.41	.21	.02	.47†	-	
12.	Mathematics	.06	.08	-.03	.41	.47	.53	.37	.24	.05	.78†	.58†	-

NOTES:
*r*s > |.03| significant at *p* < .001; Res. = resources
† Consistent with hypothesized model, correlations amongst problem-solving skill, mathematics, and science achievement are controlled for reading achievement; Gender (0 = female, 1 = male); Language Background (0 = test speaking background [TSB], 1 = non-test speaking background [NTSB])

Table 2 - *Key Parameter Estimates in Models for Individual Countries: Direct and Indirect Effects on Science and Mathematics Achievement* †

Country	Direct Effects of Arts-related ICT Use on Problem Solving			Direct Effects of Problem Solving on Science/ Mathematics Achievement††	Direct Effects of Arts-related ICT Use on Science/Mathematics Achievement			Indirect Effects of Arts-related Use of ICT on Science/Mathematics Achievement		
	Quality →PS	**Quantity →PS**	**Qual x Quant → PS**		**Quality →S/M**	**Quantity → S/M**	**Qual x Quant → S/M**	**Quality →S/M**	**Quantity → S/M**	**Qual x Quant → S/M**
Australia	.40**	-.55**	.27**	.32**/.89**	.03*/-.05**	-.01/.02	.01/-.02*	.13/.36	-.18/-.49	.09/.24
Austria	.09	-.44**	.03	.44**/.77**	.05*/-.03*	.07*/.02	.02/-.01	.04/.07	-.19/-.34	.01/.02
Belgium	.08	-.23**	.02	.27**/.84**	.01/.01	-.01/-.02	-.01/.01	.02/.06	-.06/-.19	.01/.01
Canada	.17**	-.12**	.08**	.29**/.86**	-.05**/.01	-.02**/-.01	-.03**/.01	.05/.14	-.03/-.10	.02/.07
Czech Rep.	.17**	-.24**	.06*	.24**/.95**	.01/-.01	-.05**/-.01	.01/.01	.04/.17	-.06/-.23	.01/.06
Denmark	.38**	-.47**	.19*	.46**/.91**	.01/-.03	.02/-.02	.01/-.01	.18/.35	-.21/-.42	.09/.18
Finland	.44**	-.42*	.18*	.29**/.80**	-.07/-.02	.05/-.07	-.02/.01	.13/.34	-.12/-.33	.05/.14
Germany	.08	-.21**	.01	.41**/.80**	.01/-.02	-.03*/.01	.01/.01	.03/.06	-.08/-.16	.01/.01
Greece	.09	-.24**	.01	.18**/.75**	.06*/.02	-.08**/-.01	-.01/.01	.02/.06	-.04/-.18	.01/.01
Hungary	.02	-.30**	.03	.16**/.90**	.11**/.03	-.04/.02	.03*/.02	.01/.02	-.05/-.27	.01/.02
Iceland	.20*	-.16**	.05*	.29**/.78**	.05/-.04	-.06*/-.02	.03/-.03*	.06/.15	-.05/-.13	.01/.04
Ireland	.01	-.17**	-.01	.44**/.84**	.02/-.01	-.02/-.05*	.01/.01	.01/.01	-.07/-.14	-.01/.01
Italy	.05	-.37**	.05*	.39**/.68**	.01/.01	-.05**/-.05**	.01/-.01	.02/.03	-.14/-.25	.02/.04
Japan	.12	.04	-.05	.27**/.77**	-.07/-.02	-.08/.01	-.05/-.01	.03/.09	.01/.03	-.01/.04
Korea	.26**	-.29**	.10	.46**/.77**	-.01/-.03	.01/-.03	.01/-.02	.12/.20	-.13/-.22	.05/.08
Mexico	.10**	-.28**	-.04**	.10**/.66**	.03**/.02**	-.11**/-.05**	-.02*/-.01	.01/.07	-.03/-.19	-.01/.03
New Zealand	.18**	-.28**	.04**	.40**/.78**	.02/-.01	-.06**/-.03*	-.01/-.01	.07/.14	-.11/-.22	.02/.03
Poland	.08*	-.37**	-.01	.34**/.79**	.01/-.02	-.04/-.02	-.01/-.01	.03/.07	-.13/-.29	-.01/.01
Portugal	.17**	-.35**	.06*	.28**/.86**	.05*/-.01	-.04*/-.06*	-.01/-.02	.05/.15	-.09/-.29	.02/.05
Slovakia	.24**	-.44**	.06*	.20**/.85**	-.01/-.01	-.05/-.03	.02/.01	.05/.20	-.09/-.38	.01/.05
Sweden	.13*	-.20**	.01	.17**/.79**	-.04/.01	-.06**/-.04*	-.03/.01	.02/.10	-.03/-.16	.01/.01
Switzerland	.14*	-.32**	.03	.42**/.81**	.04*/-.04*	-.05**/.02	-.01/-.01	.06/.11	-.13/-.26	.01/.03
Turkey	.07	-.03	.02	.28**/.84**	-.03*/-.04*	-.02/.01	-.01/-.01	.02/.06	-.01/-.03	.01/.01
United Kingdom	.02	-.37**	.03	.33**/.73**	.02/-.03*	.02/.01	-.01/-.01	.01/.02	-.12/-.27	.01/.02
United States	.20**	-.46**	.18**	.22**/.72**	-.01/-.01	.01/.04**	.01/-.02	.04/.14	-.10/-.33	.04/.13
Mean	**.16**	**-.29**	**.06**	**.31/.80**	**.01/-.01**	**-.03/-.01**	**-.01/-.01**	**.05/.13**	**-.09/-.23**	**.02/.05**
SD	**.12**	**.14**	**.08**	**.10/.07**	**.04/.02**	**.04/.03**	**.02/.01**	**.04/.10**	**.06/.12**	**.03/.06**

NOTES: * $p < .01$, ** $p < .001$; Significance level adjusted (via standard errors) to control for the multilevel nature of the data. †All parameters controlled for covariates (gender, age, language background, parent education, home resources). †† Parameters from problem-solving skill to science and mathematics achievement are controlled for reading ability

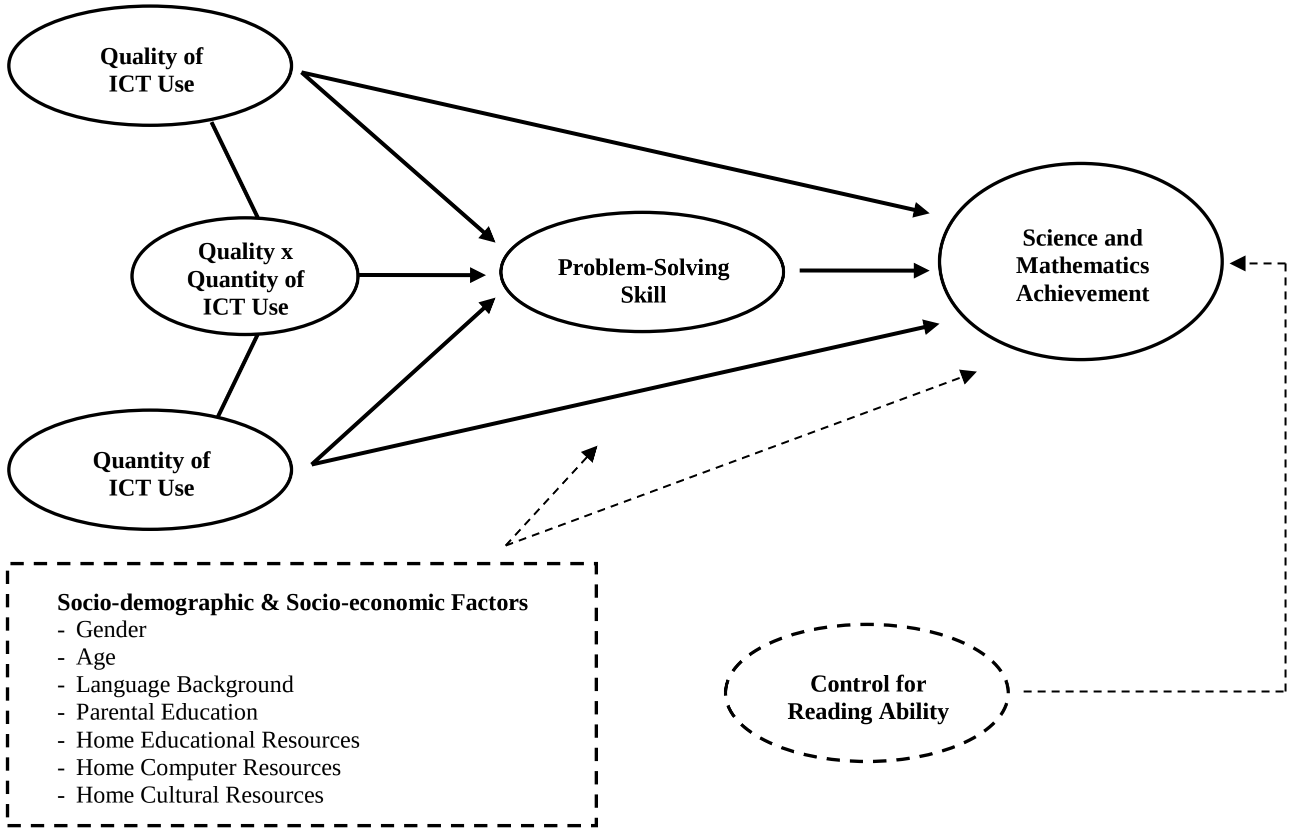

Figure 1

Hypothesized Model of Arts-related Use of ICT, Problem Solving Skill, and Science and Mathematics Achievement

NOTE: Bold paths represent target parameters; dashed box, paths, and ellipse represent control variables in the model

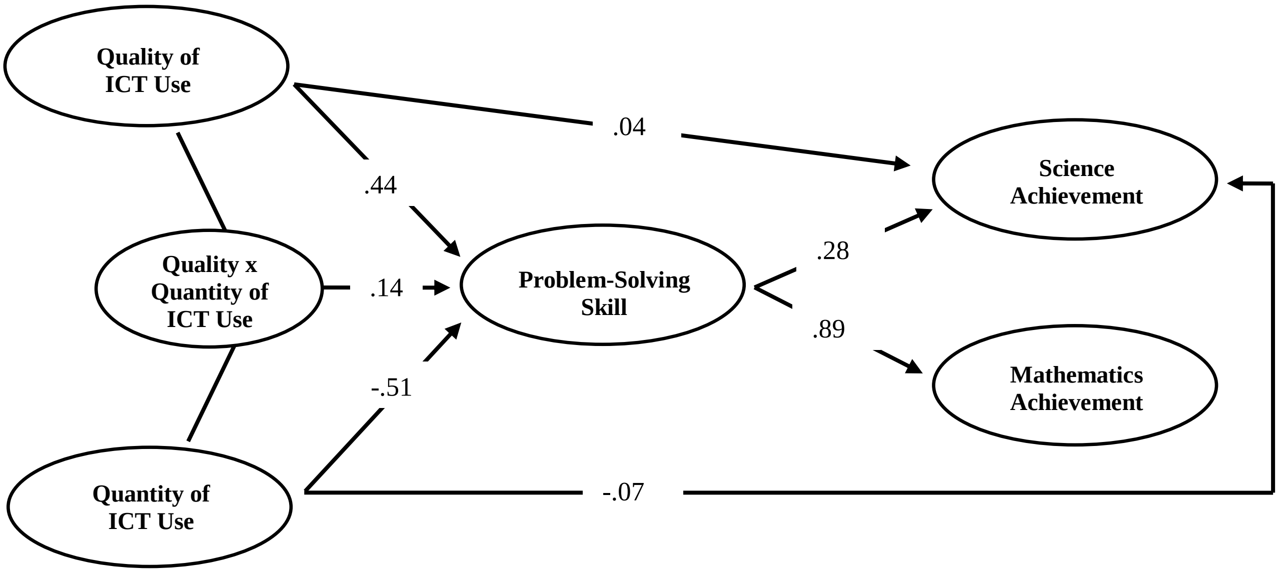

Figure 2

Significant Effects in the Model

NOTES: All paths are significant at $p < .001$ (β/standard error $\geq$ 3.29)
Non-significant paths are not shown (see Table 2 for all significant and non-significant parameters)
All parameters control for socio-demographic and socio-economic background factors
Parameters from problem-solving skill to science and mathematics achievement control for reading ability

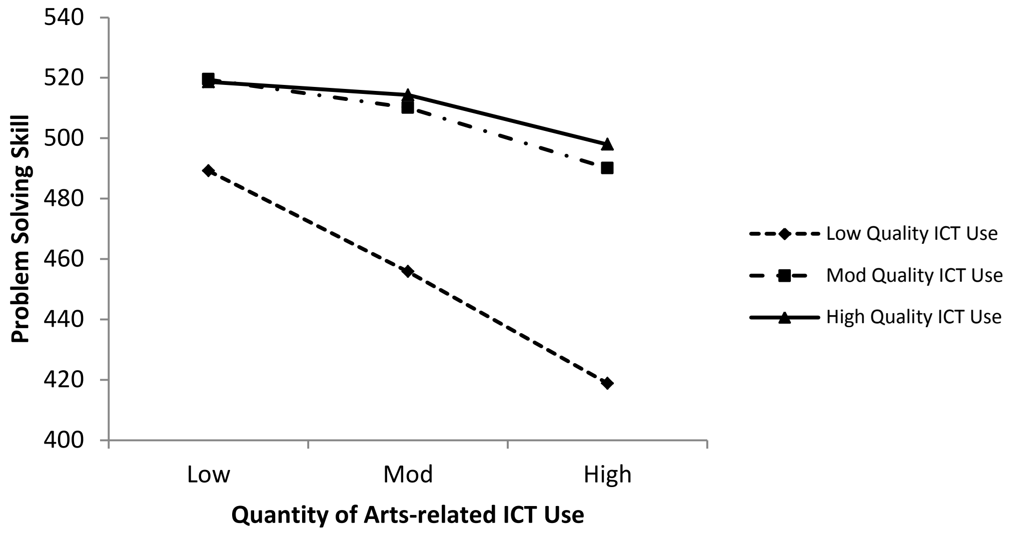

Figure 3

Interaction of Quality and Quantity of Arts-related ICT Use on Problem-Solving Skill