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PREDICTION OF DIGITAL PROBLEM-SOLVING PERFORMANCE OF THE LOW-ACHIEVERS OF A HIGH-PERFORMING ECONOMY IN PISA 2012: PERSEVERANCE, OPENNESS AND ICT USE AS QUALITY EDUCATION INDICATORS

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Abstract
In 2012, a representative sample of Macao-China's 15-year-old students participated in the Programme for International Student Assessment (PISA) 2012 Study, hosted by the Organization for Economic and Cooperation Development (OECD). Data on the problem-solving dispositions and ICT use variables affecting digital problem-solving performance were collected by digital tests and questionnaires. Because of their statistically significant correlations with digital problem-solving performance, the two problem-solving dispositions (i.e. Perseverance in problem-solving, Openness to problem-solving) and one ICT use variable (i.e. Information and communication technology use at home for school-related tasks) have been envisaged by researchers who conducted this international survey at Macao-PISA Centre as quality education indicators having potential to bring about higher level of digital problem-solving performance of all students including the low-achievers. Using quantile regression, this study seeks to examine the effect sizes of these three variables at the low-end of the digital problem-solving proficiency continuum. The findings have implications for teachers to devise intervention studies regarding raising digital problem-solving competence of Macao-China's low-achievers.

Keywords: digital problem-solving; low-achievers; quality education indicators; PISA; quantile regression

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Introduction

Since 2003, Macao-China participated in OECD's Programme for International Student Assessment (PISA). The Government hopes to make use of the survey results to inform the stakeholders (i.e. schools, teachers, students, etc.) on how to foster fundamental 21st century skills in the basic education system in preparation for the workforce in the digital age (Autor, Levy, & Murnane, 2003; Partnership for 21st Century Skills, 2011; Shiu & Ho, 2013). Complex and creative problem-solving delivered in the computer-based medium, known as digital problem-solving in the present study, is one such skill assessed in PISA 2012 (*see* Funke & Frensch, 2007; Funke, 2010; Kuo, Chen, & Hwang, 2014; Hwang & Kuo, 2015; Lai & Hwang, 2014; OECD, 2013 for some examples of this kind of assessment in the past decade). This momentous study involving 44 participating economies defined problem-solving ability as "an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious, and it includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen" (OECD, 2014a, p. 30). As seen in this definition, this ability is not linked to any particular school subjects in the basic education curriculum, and it is important that every 15-year-old student before exiting the basic education system should have equipped with this ability beyond baseline level for productive functioning in the information era of the 21st century (Cheung & Tse, 2015).

Macao-China's performance in the PISA 2012 problem-solving assessment is highly satisfactory. As seen in Table 1, Macao-China's males perform better than the females, but male's performance is a little bit less homogeneous than the female's. However, both males and females perform much better than that of the OECD average (M=500; SD=100). The differences in mean and standard deviation between males and females imply that in order to help Macao-China's low-achievers in digital problem-solving competence, there is a need to direct attention to students of different gender.

Table1. Digital problem-solving ability of Macao-China's 15-year-olds in PISA 2012

Gender	Number of students tested	Mean	SD
Male	1570	545.6	80.8
Female	1577	535.1	77.1
Total	3147	540.5	79.2

Note: Number of students sampled in the digital problem-solving assessment = 3189, covering 59% of the 15-year-olds in Macao-China's secondary school population. The response rate is 97.4%

Altogether there are 44 participating economies in the PISA 2012 digital problem-solving assessment. The survey results show that the top seven high-performing economies are all in East Asia (*see* Table 2). Singapore, Korea and Japan top the three leading positions of the league table of digital problem-solving ability, followed by the four Chinese-speaking economies, i.e. Macao-China, Hong Kong-China, Shanghai-China, and Chinese Taipei. After considering the sampling and measurement errors, Macao-China ranks amongst the 4th to 6th position in the league table of digital assessment of problem-solving ability. There is an achievement gap of more than 10 score points (estimated to be equivalent to 0.1 SD of the PISA 2012 digital problem-solving performance score, or estimated to be around 0.3 grade level of schooling, *see* OECD, 2010, p.30) between the four Chinese-speaking economies and the top three high-performing economies. In the case of Hong Kong-China, Shanghai-China and Chinese Taipei, the gaps are even larger.

Table 2. Digital problem-solving ability of the top seven high-performing economies in PISA 2012

Economy	Digital problem-solving ability score	
	Mean	SE
Singapore	562.4	1.2
Korea	561.1	4.3
Japan	552.2	3.1
Macao-China	540.5	1.0
Hong Kong-China	539.6	3.9
Shanghai-China	536.4	3.3
Chinese Taipei	534.4	2.9
OECD Average	500.1	0.7

Note: There were 65 economies participating in PISA 2012 paper-based assessment. Amongst these, only 44 economies participated in the digital assessment of problem-solving ability

Hence, from the researcher’s point of view, there is still much room for Macao-China to elevate its students’ digital problem-solving ability. Admittedly, from the comparative education perspective, because Macao-China is a high-performing economy, its students who are below the median of digital problem-solving ability distribution are still relatively high-performing than most of the participating economies in PISA 2012. However, there are still some 8% of Macao-China’s 15-year-old school population who are below the baseline level (i.e. level 2) of digital problem-solving proficiency scale. These are the low-achievers needed academic enhancement in this study.

The present study

In the past decade, many countries/economies participated in international sampled surveys of the computer-delivered 21st century skills, such as the digital reading and problem-solving skills (OECD, 2011; 2014a). The assessment results are of value to help the low-achievers to meet the challenges of the information age, and the high-performing Macao-China is of no exception. It is the intention of the Government to base on the findings of OECD's PISA to help improve the digital problem-solving abilities of the low-achieving students. To this end, Macao-PISA Centre which conducted the Macao-China PISA 2012 study put forward a number of quality education indicators which have a bearing to raise digital problem-solving abilities of the junior secondary school population (Cheung, Sit, Mak, & Ieong, 2014). Amongst the indicators put forward three are directly related to digital problem-solving, namely, *Perseverance in problem-solving* (PERSEV), *Openness to problem-solving* (OPENPS), and *Information and communication technology use at home for school-related tasks* (HOMSCH). These three variables are the foci of analyses in this study. Secondary analyses of the Macao-China data are needed to furnish nuanced information to schools so that teachers can target schooling practices precisely at the digital problem-solving learner characteristics of the low-achieving students. This study seeks to study in-depth the effects of the three problem-solving variables on digital problem-solving ability at the low end of the digital problem-solving proficiency continuum.

Conceptual model of factors affecting digital problem-solving performance

One proposal for Macao-China schools to further itself amongst the participating countries/economies is to raise the literacy performance level of the low-achievers. To do so, researchers need to base on empirically verified quality education indicators and target the classroom practices at the learner characteristics of the low-achievers. For instance, Ben-David Kolikant (2012) has discussed the reasons behind the high ICT access but somehow low use in nowadays schools in terms of the learner characteristics. In order to improve digital problem-solving ability of Macao-China's low-achievers, it is the intention of this study to examine three problem-solving disposition and ICT use variables and assess their effects at the low end of the digital problem-solving ability continuum. Figure 1 presents a conceptual model of how the three quality education indicators taken together influence digital problem-solving ability of the students. This model guides the conduct of enquiry of the present study. Because PISA 2012 is not a longitudinal study, the effects assessed are cross-sectional and they do not imply causal relationships amongst the predictor variables in the explanation of outcomes of schooling.

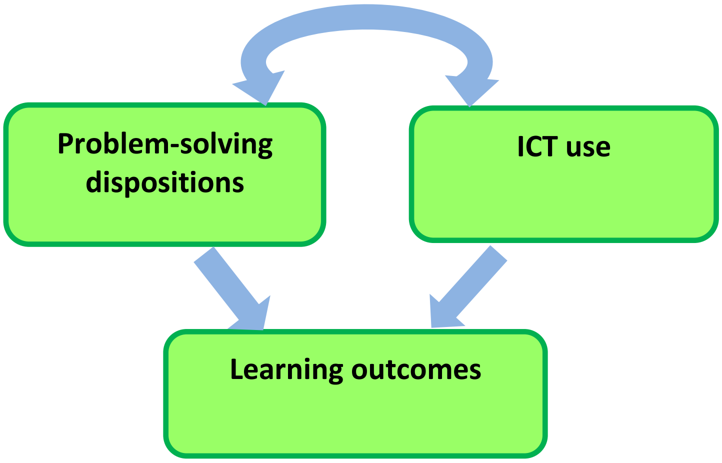

Figure 1. Conceptual model of the influence of problem-solving disposition and ICT use variables on student learning outcomes

Perseverance in problem-solving (PERSEV) is a good quality education indicator because students who are equipped with this disposition are able to persist and thrive in a changing economy (Chaplain, 2000; Murnane & Levy, 1996). Likewise, *Openness for problem-solving* (OPENPS) is an important quality education indicator with regard to complex problem solving. In PISA 2012, OPENPS is conceptualized as a fundamental dimension of personality reflecting cognitive exploration. Students who are equipped with this disposition are able to solve complex problems critically and creatively (DeYoung, 2013; McCrae & Costa Jr., 1997; Saucier, 1992). Wen (2015) has done a useful comparison of the learner characteristics of openness to problem solving of 15-year-old students of the four Chinese-speaking economies participating in PISA 2012. Last, *ICT use at home for school-related activities* (HOMSCH) has proved to be a very good quality education indicator in the prediction of digital reading literacy (Cheung, Mak, & Sit, 2013).

In this study, understanding of the dispositions and processes in operation underlying the PISA 2012 digital problem-solving proficiency scale is of importance in order to bring up digital problem-solving ability of the 15-year-old students from low- to high-level. Scrutiny of description of the proficiency level of digital problem-solving proficiency scale reveals that students with the high problem-solving ability level, compared with the low problem-solving ability level, are able to handle a lot of information, are quick to understand things, seek explanations for things, can easily link facts together, and like to solve complex problems (*see* OECD, 2014a, p. 57). PISA 2012 utilized the OPENPS scale to assess the problem-solving disposition of the sampled students. In addition, in a timed computer-delivered assessment environment in which a number of problem-solving tasks of varying difficulties are presented, students need to have perseverance in order not to give up easily. They need to remain interested in the tasks that they have started and do not put off difficult problems. When time permits, they need to continue working on tasks until everything is perfect, and do more than what are expected of them. PISA 2012 utilized the PERSEV scale so as to assess the problem-solving disposition of the sampled students.

In sum, the present study seeks to make use of Macao-China's three quality education indicators (i.e. *Perseverance in problem-solving*, *Openness to problem-solving*, and *ICT use at home for school-related tasks*) to help the low-achievers (those who are below the baseline level 2) to improve digital problem-solving ability. Based on secondary analyses of the PISA 2012 data, problem-solving characteristics of the low-achievers are analyzed in terms of the three quality education indicators, as well as a number of student's personal characteristics, like gender and ESCS (*Economic, Social and Cultural Status*). One concern of this study is to study the effects of the three quality education indicator variables at the low-end (below the median) of the digital problem-solving ability continuum. Through in-depth analyses using quantile regression, Macao-China's teachers will then know how to help raise students' digital problem-solving ability in their everyday academic studies.

Research question

Since Macao-China is a high-performing economy, percentage of males and females who are below baseline level (i.e. level 2 of the PISA 2012 problem-solving proficiency scale) remain at a very low level of 6-8%. All the students below the median of the digital problem-solving ability distribution are the target students of this study. PISA 2012 digital problem-solving assessment results, like those obtained in other cycles of PISA assessment, are of paramount importance for informed policy making (Cheung et al., 2013). In the research literature, there are two findings relevant to the purpose of this study. First, on average across the OECD countries, the association between PERSEV and performance in digital problem-solving is stronger among high-achieving students than among low-achieving students, although the associations are less marked in the case of OPENPS. Everything in the PISA 2012 data indicates that high levels of PERSEV and OPENPS work as a catalyst for the ever-higher performance among the most talented students (OECD, 2014a, p. 113). Second, compared to performance on static items, Macao-China's performance on interactive items is relatively weaker. In reviewing Macao-China's curricula, teachers and curriculum developers may want to introduce more opportunities for students to develop and exercise the two problem-solving dispositions (i.e. PERSEV and OPENPS) that are linked to success on interactive items (OECD, 2014a, p. 81, p. 91). Thus, it is of interest to see if these findings are applicable to Macao-China’s low-achievers.

Under this backdrop, the main aim of this study is to examine the association amongst variables like gender of student, ESCS, PERSEV, OPENPS and HOMSCH of the 15-year-old secondary students in Macao-China. The aim is to examine the effects of the three problem-solving disposition and ICT use variables on digitial problem-solving ability of students at the low end of the ability continuum (below the median), after controlling for the effect of gender of the student, as well as the ESCS of the student. Based on the conceptual model shown in Figure 1, the research question of this study is:

> At the low-achieving end of the digital problem-solving ability continuum (i.e. at the 10^{th}, 25^{th} and 50^{th}percentile of the digital problem-solving performance scale), after controlling for the effect of gender and ESCS of student, what are the effects of the three problem-solving disposition and ICT use variables (i.e. PERSEV, OPENPS, and HOMSCH) on digital problem-solving ability? Are these effects statistically significant? What are their estimated effect sizes?

Past research of the three problem-solving variables examined in the present study

Correlation of the three problem-solving variables

In PISA 2012 digital problem-solving assessment, two constructs pertaining to student problem-solving dispositions (i.e., PERSEV and OPENPS) are used to relate to student digital problem-solving performance (OECD, 2014a). Scaling based on Item Response Theory (IRT) reveals that the attitude item "I (do not) put off difficult problems" pertains highly to the perseverance in problem-solving scale, whereas "I like to solve complex problems" pertains highly to the openness to problem-solving scale (OECD, 2014b, p. 340). The Cronbach's Alpha reliabilities of these two constructs are 0.79 and 0.82 respectively. There is another construct, HOMSCH, developed and used as ICT use variable with potentials to enhance student digital problem-solving ability in the school curriculum. Scaling based on IRT reveals that the three items "Using email for communication with teachers and submission of homework or other schoolwork", "Downloading, uploading or browsing material from school's website", and "Checking the school's website for announcements", are the three items that pertain highly to this measurement scale (OECD, 2014b, p. 340). The Cronbach's Alpha reliability of this construct is 0.80.

For Macao-China, the Pearson correlations of these three constructs with digital problem-solving ability are 0.134, 0.248 and 0.159 respectively (Cheung et al., 2014). In total, 7.7% of performance variance can be explained by the three constructs taken together. Of note is that the three constructs are envisaged by Macao-PISA Centre as quality education indicators that may be used to improve digital problem-solving ability of Macao's 15-year-old students (Cheung et al., 2014). This pattern of correlations lends support to the conceptual model shown in Figure 1. The implication of these analysis results is that the three quality education indicators examined in this study possess satisfactory psychometric qualities in order to explain variances of digital problem-solving ability of Macao's 15-year-old students.

Effect sizes of perseverance and openness on digital problem-solving performance

To devise classroom practice for the low-achievers of a high-performing economy in digital problem-solving, there is a need to investigate closely the association between problem-solving ability and the three problem-solving disposition and ICT use variables, particularly at the low end of the ability continuum (i.e. below the median at the 10th, 25th and 50th percentile of the performance distribution). Table 3 presents the association between digital problem-solving ability and PERSEV (as well as OPENPS) of the top seven East Asian economies in PISA 2012 (OECD, 2014a, p. 217). The association at the mean is obtained through ordinary regression analysis, whereas the two associations at the 10th and 90th quantile of problem-solving ability distribution are obtained through quantile regression of the digital problem-solving performance respectively on the two PISA indices of PERSEV and OPENPS.

The data shows that the score point difference of digital problem-solving performance associated with one standard deviation unit increase in student's PERSEV and OPENPS predicted at the 10th and 90th percentile of problem solving ability scale. On average across the OECD countries, it is found that the score point differences are higher for OPENPS than PERSEV, and for the two measures they are also higher at the 90th than at the 10th percentile. Table 3 also reveals that the associations between digital problem-solving ability and PERSEV (or OPENPS) are quite varied across the top seven high-performing East Asian economies.

Table 3. Associations between problem-solving ability and perseverance in and openness to problem-solving

Economy	Score point difference associated with student's perseverance in problem solving, by performance decile in problem solving						Score point difference associated with student's openness to problem solving, by performance decile in problem solving					
	Mean		10th percentile		90th percentile		Mean		10th percentile		90th percentile	
	Score dif.	SE	Score dif.	SE	Score dif.	SE	Score dif.	SE	Score dif.	SE	Score dif.	SE
Singapore	13	2.1	13	3.6	11	4.4	18	2.0	12	4.4	20	3.3
Korea	20	2.9	21	5.1	19	5.4	37	2.3	39	4.0	29	4.1
Japan	14	2.5	13	3.7	16	3.2	23	2.3	22	3.9	23	2.6
Macao-China	13	1.9	14	4.6	11	3.7	22	1.5	23	3.3	19	3.2
Hong Kong-China	7	2.6	12	4.4	3	4.7	22	2.1	21	4.0	23	4.5
Shanghai-China	9	2.1	8	3.7	7	3.9	26	2.0	26	2.9	23	3.3
Chinese Taipei	13	1.7	10	4.4	11	3.6	21	1.7	17	3.3	22	3.7
OECD average	15	0.4	13	0.9	16	0.7	25	0.4	18	0.9	30	0.7

Source: OECD (2014a, p. 217)

For Macao-China, the score point differences are higher at the 10th than at the 90th percentile for both PERSEV and OPENPS, though the magnitude of the score point difference is higher for OPENPS than PERSEV. The implication of these analysis results is that Macao-China's classroom practice, if targeted at the low-achievers, is potentially bringing about greater educational benefits than that of the high-achievers in digital problem-solving ability. This study will adopt quantile regression analysis to study the effects of the three quality education indicators at the low end (i.e. below the median at the 10^{th}, 25^{th}, and 50^{th} of the digital problem-solving ability continuum).

Effect size of ICT use at home on digital problem-solving performance

One potential classroom practice in student's everyday school curriculum concerns with the enhancement of ICT use at home for school-related tasks. Table 4 presents the association between performance in problem-solving and use of a computer for students who use a desktop, laptop or tablet computer at home (OECD, 2014a, p. 219). This score point difference has been adjusted for student personal and demographic characteristics, so that it is possible to compare the statistics across the top-seven East Asian economies. Unlike PERSEV and OPENPS, no previous research has been conducted on digital problem-solving performance at either end of the ability continuum. The implication of these analysis results is that HOMSCH is able to explain substantially the variance of digital problem-solving ability of Macao-China's 15-year-old students, although its effect (score point difference= 33), like other high-performing economies in PISA 2012, is a little bit lower than that of the average (=39) of the OECD countries.

Table 4. Association between performance in problem-solving and students who use a desktop, laptop or tablet computer at home

Economy	Score point difference	SE
Singapore	24	5.7
Korea	33	4.2
Japan	24	3.9
Macao-China	33	8.0
Hong Kong-China	42	10.8
Shanghai-China	24	5.7
Chinese Taipei	25	7.9
OECD average	39	2.5

Note: The score point difference in problem-solving performance, independent effect of one unit increase in ICT use at home, after accounting for socio-demographic characteristics of students, corresponds to the coefficient from a regression where the PISA index of economic, social and cultural status (ESCS), ESCS squared, boy, and an immigrant (first generation) dummy are introduced as further independent variables.
Source**:** OECD (2014a, p. 219).

Method

Participants

PISA 2012 for Macao-China was essentially a census of all 15-year-old students studying in secondary schools. All the 45 schools and 5397 students who were 15-year-old at the time of assessment participated in the paper-based assessment. However, only a sample of these students took the digital assessment of problem-solving at the same time. Number of students sampled in the digital assessment was 3189, covering 59% of the 15-year-olds in the Macao-China's secondary school population (Cheung et al., 2014). Those 41% not administered the digital assessment would also have a digital problem-solving ability score. This was done through imputation based on the equated performance in other domains of the PISA paper-based assessment (for details, *see* OECD, 2014b).

Instruments

PISA 2012 digital problem-solving study employed tests and questionnaires administered in computer-delivered platforms in its data collection. PISA digital problem-solving ability score (DPSPVs) is the performance score (in the form of 5 plausible values) of the participants. It is obtained through scaling of the item responses of digital problem tasks. Apart from the two problem-solving disposition and one ICT use variables, information on gender and the ESCS of the students are also gathered through the student questionnaire. The predictor variables derived from the student questionnaire in the explanation of the variance of DPSPVs are summarized as follows:

Gender of student (GENDER): 0=female; 1=male.

Economic Social and Cultural Status (ESCS). This index is derived from three indices: highest occupational status of the parents, highest educational level of parents, and home possessions. It has been standardized across the OECD countries, with M=0 and SD=1.

Perseverance in problem-solving (PERSEV). This is constructed using student response over whether they report that statements such as "I put off difficult problems" described them very much, mostly, somewhat, not much, and not at all like them. For greater clarity of interpretation of the analysis results to the policy-makers and educational practitioners, the original 5-point Likert-type response scale has been remapped into a 3-point scale: "Very much/Mostly like me (3)", "Somewhat like me (2)", and "Not much/Not all like me (1)". Because of the special research design of PISA 2012, i.e. a sampled student is assigned one of the three student questionnaires to answer, hence one third of the data are missing by design. Proper treatment of missing data is needed in the analysis of the data.

Openness to problem-solving (OPENPS). This is constructed using student responses over whether they report that statements such as "I like to solve complex problems" described them very much, mostly, somewhat, not much, and not at all like them. For greater clarity of interpretation of the analysis results to the policy-makers and educational practitioners, the original 5-point Likert-type response scale has been remapped into a 3-point scale: "Very much/Mostly like me (3)", "Somewhat like me (2)", and "Not much/Not all like me (1)". Because of the special research design of PISA 2012, i.e. a sampled student is assigned one of the three student questionnaires to answer, hence one third of the data are missing by design. Proper treatment of missing data is needed in the analysis of the data.

ICT use at home for school-related tasks (HOMSCH). This index is constructed using student responses over whether they report that statements such as "Using email for communication with teachers and submission of homework or other schoolwork" described them very much, mostly, somewhat, not much, and not at all like them (*see* Eynon & Malmberg, 2011 for a typology of youngster's internet use). For the purpose of this study, the original 5-point Likert-type response scale has been remapped into a 3-point scale: "Almost every day or Everyday (3)", "Once or twice a month or a week (2) ", and "Never or hardly ever (1)". Unlike the previous two disposition measures, there is no missing data (by design) for this process measure from the optional ICT questionnaire in PISA 2012.

Procedures and design

To answer the research question of this study, quantile regression is conducted using PERSEV, OPENPS and HOMSCH as predictors, individually as a start and later jointly in the final full model. Score point differences of digital problem-solving performance below the median at the 10th, 25th and 50th percentile of digital problem-solving ability scale are examined for their statistical significant independent effects (p<.05) on digital problem-solving performance. This research question answers whether it is fruitful to base the classroom practice on the problem-solving disposition and ICT use variables at the low end of the digital problem-solving continuum. Treatment of plausible values of digital problem-solving performance scores is needed in the analyses (Wu, 2005).

Results

Table 5 reveals that after controlling for the effect of GENDER and ESCS of student, the independent effect of PERSEV on digital problem-solving performance at the 10^{th}, 25^{th} and 50^{th} percentile of the low end of the digital problem-solving ability continuum are all statistically significant (p<.05). The same is true for OPENPS and HOMSCH. Amongst the three disposition and ICT use variables, the effects concerned are largest for OPENPS. The effect size of the independent effects of the three disposition and ICT use variables in PISA 2012 may be considered as fairly educationally significant, amounting 0.1 SD to 0.2 SD of the distribution of the digital problem-solving performance scores.

Table 5. Quantile regression of individual quality education indicator on digital problem-solving performance

Model	Perseverance in problem-solving		Openness to problem-solving		Use of ICT at home for school-related tasks	
	Variable	Mean (SE)	Variable	Mean (SE)	Variable	Mean (SE)
10^{th} percentile	Intercept	446.6 (6.26)*	Intercept	455.2 (5.67)*	Intercept	443.9 (3.90)*
	ESCS	11.6 (3.71)*	ESCS	7.9 (3.79)*	ESCS	7.5 (2.59)*
	GENDER	2.7 (6.95)	GENDER	0.5 (6.75)	GENDER	7.2 (5.50)
	PERSEV	11.3 (4.20)*	OPENPS	20.6 (4.40)*	HOMSCH	11.5 (2.72)*
25^{th} percentile	Intercept	497.1 (2.89)*	Intercept	505.2 (3.54)*	Intercept	494.7 (3.46)*
	ESCS	12.5 (2.57)*	ESCS	8.7 (2.66)*	ESCS	8.8 (2.16)*
	GENDER	5.7 (4.00)	GENDER	2.6 (4.01)	GENDER	9.7 (3.24)*
	PERSEV	11.4 (2.81)*	OPENPS	21.0 (2.13)*	HOMSCH	13.6 (2.23)*
50^{th} percentile	Intercept	548.4 (2.54)*	Intercept	555.2 (2.71)*	Intercept	546.2 (2.77)*
	ESCS	10.1 (1.95)*	ESCS	6.8 (2.04)*	ESCS	7.6 (1.76)*
	GENDER	8.8 (3.86)*	GENDER	6.3 (3.91)	GENDER	13.1 (3.22)*
	PERSEV	12.5 (2.61)*	OPENPS	21.6 (2.23)*	HOMSCH	15.3 (2.45)*

Note: *p<.05

Table 6 shows that when all the three problem-solving disposition and ICT use variables are in operation (i.e. the *Full Model*) the independent effects of PERSEV, respectively at the three percentile locations of the low end of the digital problem-solving ability continuum, become statistically non-significant (p>.05). The independent effects of OPENPS on digital problem-solving ability, as well as HOMSCH, on digital problem-solving ability, remain statistically significant (p<.05). These two independent effects are all fairly educationally significant, with effect size equivalent to approximately 0.2 SD and 0.1 SD for OPENPS and HOMSCH respectively. The *Final Model* shown in Table 6 reveals that OPENPS and HOMSCH remain to have statistical significant independent effects (p<.05) on digital problem-solving ability at the low-end of the ability continuum. Of note is that the effect size of the independent effect of OPENPS nearly doubles that of HOMSCH. These results have implications for the design of classroom practices so as to improve the digital problem-solving abilities of the low-achieving students, i.e. s*tudents should be provided with ample opportunities to engage in the use of ICT at home for school-related tasks, and the tasks assigned should afford students ample opportunities to solve problems with an open mind.*

Table 6. Quantile regression of all three quality education indicators on digital problem-solving performance (Full and Final model)

Model	Variable	Full Model	Final Model
		Mean (SE)	Mean (SE)
10th percentile	Intercept	455.1 (6.64)*	454.7 (6.21)*
	ESCS	6.3 (3.91)	6.5 (3.71)
	GENDER	1.4 (7.38)	2.0 (7.48)
	PERSEV	-0.7 (4.95)	-
	OPENPS	19.5 (4.07)*	19.0 (3.78)*
	HOMSCH	10.1 (3.58)*	10.1 (3.49)*
25th percentile	Intercept	505.1 (4.08)*	504.9 (3.83)*
	ESCS	7.2 (2.65)*	7.3 (2.66)*
	GENDER	3.4 (4.26)	3.5 (4.25)
	PERSEV	-0.9 (2.68)	-
	OPENPS	19.9 (3.02)*	19.3 (2.55)*
	HOMSCH	10.3 (2.97)*	10.2 (2.96)*
50th percentile	Intercept	555.1 (2.98)*	554.5 (2.82)*
	ESCS	5.0 (2.04)*	5.1 (1.97)*
	GENDER	7.3 (4.16)	7.5 (4.15)
	PERSEV	-1.9 (3.04)	-
	OPENPS	20.8 (2.86)*	20.0 (2.22)*
	HOMSCH	11.9 (2.79)*	11.8 (2.60)*

Note: *p<.05

Discussion of the findings

Macao-China participated in the digital assessment of problem-solving ability of 15-year-old students in PISA 2012 Study. Although its performance results are highly satisfactory, there is ample room for improvement of the low-achievers at the *lowest* end of the ability continuum. Since the three problem-solving disposition and ICT use variables examined in the present study are quality education indicators reported by Macao-PISA Centre to have potentials for the betterment of basic education in Macao-China (Cheung et al., 2014). Promoting student's perseverance in problem-solving, openness to problem-solving, and ICT use for school-related tasks at home are expected to bring about higher level of digital problem-solving ability of Macao-China's school population. The research question addressed in this study is meant to take a nuanced look at the effectiveness of the three quality education indicators at the low end of the digital problem-solving ability continuum. Delineated below are the implications of this study.

While the three problem-solving disposition and ICT use variables have statistically significant effects on digital problem-solving ability individually, only openness to problem-solving, or ICT use at home for school-related tasks, has independent effect when all three quality education indicators are jointly in operation. This finding is arrived at after controlling for the effect of GENDER and ESCS of the student. Hence, Macao-China teachers should focus on these two empirically verified problem-solving disposition and ICT use variables when classroom practices are designed. *The design principle is such that the school-related tasks done with ICT use at home should be mind-on activities imbued with ample opportunities developing students' disposition of openness to problem-solving* (*see* DeYoung, 2013).

In Macao's everyday lessons, according to Biagi & Loi (2013), there may be four kinds of ICT activities provided to the students: (1) gaming; (2) collaboration and communication; (3) information management and technical operations; and (4) creation of content/knowledge and problem-solving activities. "Browsing the Internet for schoolwork" and "Doing homework on a computer" are two basic activities of (3) and (4) mentioned above. Research on ICT use at home conducted in the past decade reveals that effective home-school links should be established in order to permeate the boundary between ICT use at school and at home (Kent & Facer, 2004). Specifically, due attention should be paid to home experiences of ICT, as well as benefits of informal learning with ICT (Lewin, 2004).

Regarding the effective ICT use at home for school-related tasks, students need guidance to become self-efficacious and self-disciplined in their studies (Appel, 2012; Lee, 2006). In the literature, Kerawalla and Crook (2002) have found that children spent most of their time on games not typically found in classrooms, and parents took few steps to orchestrate the content of their children's computer activities. Additionally, Yellowlees and Marks (2007) raised issues of internet addiction and problematic internet use, since it was found that some students were having problematic Internet use in relation to specific online activities. Last, but not the least, Wittwer and Senkbeil (2008) found that it does not matter how often students use a computer at home; the key is that students use the computer in a self-determined way that largely engages them in problem-solving activities.

Strategies for supervising students may be different between the two sexes. In the literature, Imhof, Vollmeyer, and Beierlein (2006) reported that males spent more time at the computer for personal purposes than females. In online reading environments, males and females also differed significantly on selective reading and sustained attention (Liu & Huang, 2008). Volman et al. (2005) noted that there are gender differences in ICT use at school due to accessibility and attractiveness of different types of ICT applications. Females and males take on different tasks when working together on the computer, and they tackle ICT tasks differently. Outside school, significant gender differences in frequency and type of computer use are also found. These findings highlight the need for educational interventions that focus on social practices communicating gendered expectations to youngsters of the two sexes (Vekiri & Chronaki, 2008).

Last, but not the least, Mayer and Wittrock (2006) have remarked that motivational and affective factors have been found to be associated with problem solving. Guided by the conceptual model of this study, this study confirms that *openness to problem-solving* and *perseverance in problem-solving* are two very important problem-solving dispositions that have a bearing on students' digital problem-solving abilities (*see* De Bortoli & Macaskill, 2014). As both of these two disposition variables are quality education indicators, meaning that higher level of openness and perseverance will contribute uniquely and/or jointly to student digital problem-solving performance. To elevate students' openness to problem-solving, in Macao's schooling contexts, teachers can empower students to handle a lot of information, train them up to be quick to understand things, be patient to allow them time providing explanations to things, initiate them into the habits linking facts together, and make efforts fostering student interests to solve complex problems. To increase students' perseverance in problem-solving, during problem-solving activities, teachers should encourage students to persist and not to give up easily. Students should continue working on tasks until they are satisfied with it. The most important message conveyed to students is to ask them to remain interested in the tasks that have started, and do more than what is expected on them.

Conclusions

This study confirms the vision of researchers at Macao-PISA Centre to view the three disposition and ICT use variables as quality education indicators applicable in Macao's basic education schooling contexts. That the low-performing students should be provided with ample opportunities to engage in the use of ICT at home for school-related tasks, and the tasks assigned should afford students ample opportunities to solve problems with an open mind is a new finding in Macao-China's effective schooling literature.

The main conclusion of this study is that teachers and schools should render assistance to the low achievers in accordance with students' zone of proximal development. Low-achievers should be provided with ample opportunities to use ICT at home for school-related tasks. ICT-enriched learner-centered environments should be created and heavy users of computer games and social media need to be counselled. Through proper guidance and counseling by teachers, parents and peers, students are initiated and modeled not to give up easily when confronted with problems. Furthermore, they learn the many sound pedagogical ways to be open-minded to problem-solving scenarios, and their minds become more receptive to solving the problems assigned to them, or encountered in daily life. To this end, the quantile regression results help estimate the effect size of the problem-solving disposition and ICT use variables across gender on digital problem-solving ability at the low end of the digital problem-solving continuum, after taking into account the ESCS of the students.

The limitation of this study is that PISA 2012 digital problem-solving study is a cross-sectional sampled survey, not a longitudinal study of student development of digital problem-solving ability. The conclusions stated above regarding the effects of the disposition and ICT use variables are needed to be further materialized and substantiated by other well-designed intervention studies targeted at raising the digital problem-solving ability of the low-achievers.

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