Problem-Solving Attitudes and Gender as Predictors of Academic Achievement in Mathematics and Science for Canadian and Finnish Students in the PISA 2012 Assessment

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Abstract: This study aims to understand the predictive role of attitudes towards problem solving, such as perseverance and openness for problem solving, as well as of gender and country for Canadian and Finnish students' academic achievement in mathematics and science. We examined the data of students from Canada (n = 21,544) and Finland (n = 8,829) who participated in the 2012 Programme for International Student Assessment (PISA). Hierarchical multiple regression analyses revealed that *openness for problem solving* and *perseverance* were positively related to mathematics and science scores in PISA 2012. In mathematics, Canadian females were outperformed by Canadian males and by Finnish females and males. In science, females outperformed males and Finnish students outperformed Canadian students. Results imply that interventions on attitudes towards problem solving could reduce the academic achievement gender gap in mathematics and science.

Keywords
problem solving, perseverance, openness for problem solving, mathematics, science, gender, Canada, Finland, PISA

Introduction

Problem solving constitutes a major component of learning in academic disciplines, such as science, technology, engineering, and mathematics (STEM). As STEM programs continue to focus more on critical thinking and problem-solving skills than on factual knowledge, assessments of problem-solving skills and attitudes, as well as of their impact on other subject areas (e.g., mathematics and science) have begun to receive more attention. The Organisation for Economic Co-operation and Development (OECD, 2017) has recently started to examine students' creative problem solving, as well as their attitudes towards problem solving, such as perseverance and openness for problem solving (OECD, 2013; OECD, 2014; PISA, 2013). For instance, in 2012, the *Programme for International Student Assessment* (PISA) included a set of cognitive problem-solving items as a separate test, as well as several items in the *Student Questionnaire* surveying students' attitudes towards problem solving. Specifically, two new indices that measure motivational and affective factors, *perseverance* (i.e., students' self-perception of their attitudes towards difficulties encountered during a problem-solving activity) and *openness for problem solving* (i.e., students' self-perception of their willingness to solve complex problems), were included for the first time to emphasize the paramount importance of assessing problem-solving attitudes alongside the cognitive skills already included in the PISA assessment (e.g., mathematics, science, and reading literacy).

PISA is a large-scale international assessment of competencies that has been administered triennially to 15-year-old students from the OECD member countries and other partner countries since 2000. It includes a two-hour paper-based test that evaluates students' knowledge and cognitive skills in mathematics, science, and reading needed for a successful adult life, rather than students' mastery of the school curriculum in these subjects. The tests combine open-ended and multiple-choice questions grouped under real-life scenarios. In 2012, PISA focused on mathematics and was administered to 510,000 students between the ages of 15 years 3 months and 16 years 2 months in 65 countries or economies representing 80% of the world's economy (OECD, 2013).

This study examines the data from the 2012 PISA assessment for students from Canada and Finland, two developed countries from North America and Europe, respectively, committed to promoting gender equality (Baker & LeTendre, 2005; Gurría, 2011). Researchers often argue that educational systems based on equity and access to high-quality instruction for all students may lead to more academic success than those based on competition and incentives (Darling-Hammond, 2012). Thus, the study explores the role of gender in the relation between students' attitudes towards problem solving and their achievement in mathematics and science in two progressive countries consistently achieving scores significantly above the OECD average in the three core subjects assessed. The study investigates if students' gender and attitudes toward problem solving in these countries play a role in students' academic achievement in mathematics versus science, posing the following research question:

Do perseverance, openness for problem solving, gender, and country predict the academic achievement in mathematics and science of Canadian and Finnish students in the PISA 2012 assessment?

The following sections include a review of the relevant literature, a description of the PISA assessments, the methodology employed to analyze the data, and a discussion of the findings, limitations, and future research directions.

Literature Review

Problem solving is considered an essential 21st-century skill associated with academic achievement (Sonnleitner, Keller, Martin, & Brunner, 2013; Wirth & Klieme, 2003; Wüstenberg, Greiff, & Funke, 2012). Examining the problem-solving process is important in aiding students' academic achievement and in gaining insights into potential differences due to individual characteristics (e.g., gender). Problem solving is ultimately important for participating in the workforce and economy, but problem-solving skills are often lacking in most new hires (Hart Research Associates, 2015). At the same time, gender equality needs to be ensured in the workforce of a highly-technological society in which current estimates suggest that only 14.1% of North American computer science bachelor's degree graduates are female (Zweben & Bizot, 2015). This process needs to start early, because research suggests that students make decisions regarding their future commitment to STEM fields as early as middle school (Tai, Liu, Maltese, & Fan, 2006). Many countries have embraced computational thinking (Grover & Pea, 2013; Grover, Pea, & Cooper, 2015; Wing, 2006) as a way to equip students with the problem-solving tools needed to succeed in navigating the complexities of the 21st-century challenges (e.g., global warming, global epidemics, etc.). For example, in 2014, the UK withdrew their integrated Information and Communication Technology (ICT) curriculum and replaced it with a comprehensive K-12 computational thinking (CT) curriculum (Furber, 2012). Major initiatives to train US teachers are under way: in New York City, all public schools will offer computer science courses in ten years, while San Francisco schools will offer computer science courses from pre-kindergarten to high school, making it mandatory up to eighth grade (Taylor & Miller, 2015). Notably, computational thinking highlights the concerted development of both the skills, such as abstraction, decomposition, sequencing, and the attitudes necessary for solving complex problems, such as tolerance for ambiguity, persistence, collaboration (Computer Science Teachers Association, 2011). Researchers argue that student learning must be assessed through multiple measures or "systems of assessments" that take into account both the cognitive and the non-cognitive aspects of computational thinking (Grover, 2017). For instance, in a longitudinal study sampling 14,000 Swedish men (Lindqvist & Vestman, 2011), researchers found that non-cognitive abilities, including persistence, had a greater impact than cognitive abilities on future labour market success (Cai et al., 2017). Concomitantly, researchers found that even though women and men displayed similar performance, such as similar scores on a science exam, they displayed different attitudes towards their performance, such as women underestimated while men overestimated their performance (Ehrlinger & Dunning, 2003). Therefore, the role of gender in developing problem-solving skills and succeeding academically cannot be neglected. The relation between students' academic achievement and attitudes towards problem solving was extensively explored. We distinguish several positive associations, negative associations, as well as no associations in the relevant literature.

Positive Associations. A meta-analysis found evidence of a positive relationship between mathematics-related attitudes and mathematics performance, with no gender effect on this relationship (Ma & Kishor, 1997). Recently, non-cognitive factors have been increased studies in association with achievement in mathematics education research (Middleton, Jansen, & Goldin, 2017). Success in mathematical problem solving was also influenced by students' self-regulation strategies, emotions, and beliefs while performing or applying a mathematical task (Chiu, 2012; Viholainen, Asikainen, & Hirvonen, 2014). In another study, a positive association was found between attitudes toward mathematics and mathematics grades, over and above students' cognitive ability and personality dimensions (Lipnevich, Preckel, & Krumm, 2016). In a study focused on PISA 2006, researchers found that although the use of ICT use was a significant negative predictor of mathematics, students' confidence in performing ICT activities was a significant positive predictor of mathematics (Güzeller & Ayça, 2014). Finally, self-efficacy was found to be a predictor of mathematics performance (Pajares & Miller, 1994).

Negative Associations. The study conducted by Ehrlinger and Dunning shows that self-assessment may not indicate actual performance in science (Ehrlinger & Dunning, 2003). Other findings suggest that students' negative attitudes towards mathematics can lead to a worse performance in mathematics (Cifarelli, Goodson-Espy, & Chae, 2010). A study examining the PISA 2006 data collected from Turkish students revealed that achievement in mathematics was negatively associated with self-reliance in performing ICT high-level tasks, such as programming or using advanced software (Ziya, Doğan, & Kelecioğlu, 2010).

No Associations. A meta-analysis on the effects of science and mathematics teaching on attitudes and achievement found no correlation between the effect of an intervention on attitude and its effect on achievement (Savelsbergh et al., 2016). Also, several empirical studies found no gender differences in attitudes toward problem solving (Salleh & Zakaria, 2009).

Taken together, these results prompt further exploration of the factors that are associated with academic achievement, including the role of gender in the dynamics of achievement and students' attitudes toward problem solving.

Student Questionnaire

The *Student Questionnaire* is an instrument that complements the assessments for testing reading, mathematics, and science skills. This instrument collects students' background information and aims to assess, among other aspects, students' attitudes towards problem solving. In PISA 2012, several attitude indices were computed based on the information obtained from the Student Questionnaire using item response theory models. The detailed descriptions of these indices and statistical procedures used to create them can be found in the PISA 2012 Technical Report (PISA, 2014). All of the variables employed in the following analyses were derived from the Student Questionnaire in PISA 2012.

Methods

Participants and Procedure

This study focuses on a sample of participants in the PISA 2012 administration illustrated in Table 1. The PISA 2012 assessment consisted of a stratified random sample of 21,544 Canadian students randomly selected from 885 middle schools in Canada and of 8,829 Finnish students randomly selected from 311 middle schools in Finland. The proportions of male and female students were very similar within and between countries, as shown in Table 1.

Table 1. PISA 2012 participants from Canada and Finland

Country	Number of Students		
	Total	Female	Male
Canada	21,544	10,943 (50.8%)	10,601 (49.2%)
Finland	8,829	4,370 (49.5%)	4,459 (50.5%)

Measures

Two measures of the attitudes towards problem solving (perseverance and openness for problem solving) and two demographic measures (country, gender) were employed to predict students' academic achievement in mathematics and science (see Table 2). These variables are described in detail further in this section.

Table 2. Indices for problem-solving attitudes and demographic information that were included in the analyses

Index	Description
PERSEV	Perseverance
OPENPS	Openness for problem solving
COUNTRY	Country, which we coded as 1 for Canada and 0 for Finland
GENDER	Gender, which we coded as 1 for female and 0 for male students
Math	Average mathematics literacy score
Science	Average science literacy score

Perseverance

Perseverance (PERSEV) was measured using five items included in the Student Questionnaire. Each item had five response categories: “Very much like me”, “Mostly like me”, “Somewhat like me”, “Not much like me” and “Not at all like me” (PISA, 2014). Table 3 shows the items from the Student Questionnaire related to the construct of perseverance.

Table 3. Items for the perseverance (PERSEV) index

Item	How well does each of the following statements below describe you?
ST93Q01	a) When confronted with a problem, I give up easily
ST93Q03	b) I put off difficult problems
ST93Q04	c) I remain interested in the tasks that I start
ST93Q06	d) I continue working on tasks until everything is perfect
ST93Q07	e) When confronted with a problem, I do more than what is expected of me

Openness for Problem Solving

Openness for problem solving (OPENPS) was measured using five items included in the Student Questionnaire. Each item had five response categories: “Very much like me”, “Mostly like me”, “Somewhat like me”, “Not much like me” and “Not at all like me”. Table 4 shows the items related to openness for problem solving.

Table 4. Items for the *openness for problem solving* (OPENPS) index

Index	How well does each of the following statements below describe you?
ST94Q05	a) I can handle a lot of information
ST94Q06	b) I am quick to understand things
ST94Q09	c) I seek explanations for things
ST94Q10	d) I can easily link facts together
ST94Q14	e) I like to solve complex problems

Both *perseverance* and *openness for problem solving* indices were estimated using the Rasch scaling methodology in PISA 2012. Each index typically ranges from -4 to 4 on a logarithmic scale. Higher and positive values indicate higher levels of the latent trait being measured by each of those indices (i.e., higher perseverance and more openness for problem solving). The mean indices of perseverance and openness for problem solving are summarized in Table 5, showing that males significantly outperform females and Canadian students significantly outperform Finnish students on both self-reported measures (De Bortoli & Macaskill, 2014).

Table 5. PISA 2012 participants’ *perseverance* and *openness for problem solving* indices

Country	Attitudes Towards Problem Solving Mean (SE)					
	Perseverance			Openness for Problem Solving		
	All	Female	Male	All	Female	Male
Canada	.22 (.01)	.19 (.02)	.25 (.02)	.14 (.01)	.02 (.02)	.26 (.02)
Finland	.00 (.02)	-.07 (.02)	.07 (.02)	-.11 (.02)	-.21 (.02)	.00 (.03)

Country, Gender, and Academic Achievement

The dependent variables included in the study are *Math* and *Science*. In PISA, instead of a single test score in each subject area, five plausible scores are estimated for each student from the posterior distributions of achievement. The averages of the five plausible values from students' PISA 2012 mathematics and science assessments were used as the dependent variables that represent the overall achievement in mathematics and science, respectively. The independent variables representing *Perseverance, Openness for Problem Solving*, *Country*, and *Gender* were used to predict mathematics and science achievement using a hierarchical multiple regression approach. Table 6 provides a descriptive summary of the demographic and achievement variables used in this study across Canada and Finland overall and by gender.

Table 6. Descriptive statistics (means and standard deviations) for the mathematics and science scores by gender and country

Country	Gender	Subject Mean (SD)	
		Math	Science
Canada	Female	504.91 (81.40)	513.72 (83.23)
	Male	514.07 (88.08)	515.22 (91.43)
	All	509.42 (84.87)	514.46 (87.36)
Finland	Female	506.85 (83.51)	534.04 (91.65)
	Male	507.79 (89.97)	521.42 (99.11)
	All	507.33 (86.83)	527.66 (95.69)
Canada and Finland	Female	505.47 (82.01)	519.52 (86.20)
	Male	512.21 (88.69)	517.05 (93.81)
	All	508.81 (85.45)	518.30 (90.06)

Analyses

This study examines the role that gender, country, and problem-solving attitudes play in students' academic achievement in mathematics and science. The analyses also examine the interaction between country and gender (country*gender), given the disparate averages reported in Table 6. Data analyses were conducted using a weighted least square hierarchical regression analysis. We built models in which the independent variables (Country, Gender, Country*Gender, Perseverance, and Openness for Problem Solving) were used successively in regressions to predict the dependent variable (mathematics and science scores, respectively). In the first block of the hierarchical multiple regression (Model 1), we entered country, gender, and the interaction between country and gender, country*gender, to predict mathematics and science, respectively. In the second block (Model 2), we added perseverance and openness for problem solving to examine their predictive capacity of academic skills, above and beyond the demographic variables in the first block. Student sampling weights provided in the PISA 2012 database were included in the regression analyses. In all analyses, Finland represents the reference group for Country, while male represents the reference group for Gender. All analyses were conducted in SPSS (IBM Corp., 2013). The results of these analyses are described in the next section.

Results

Mathematics Achievement

The hierarchical regression analysis indicates that the regression model comprising the demographic variables employed to predict mathematics literacy (Model 1) is significant [F(3,19754) = 33.127, $p < .001$] but it explains a very small proportion of the variance in mathematics scores, R^2 = Adjusted R^2 = .005. Results show that, although Country and Gender are not significant predictors, their interaction is significant (t = -2.98, $p < .01$), as shown in Table 7 (Model 1). This indicates that Canadian females were significantly outperformed by all other groups (Canadian males, as well as Finnish females and males) in mathematics achievement, also corroborated by Table 6. The model comprising both the demographic variables and the problem-solving attitudes (Model 2) is also significant [F(5,19752) = 1001.143, $p < .001$] and it explains a significant proportion of the variance in mathematics scores, R^2 = Adjusted R^2 = .202. This large difference in the Adjusted R^2 values between models indicates that the problem-solving attitudes play a crucial role in students' mathematics achievement, above and beyond demographic factors. Moreover, adding problem-solving attitudes to the model significantly increases the model's capacity to predict mathematics, as well as the percentage of explained variance in mathematics scores by 20%. The interaction between country and gender remains significant in Model 2. When openness for problem solving and perseverance are added to the model, we found that country, but not gender, significantly predicted mathematics scores, as shown in Table 7 (Model 2). This finding indicates that Canada is outperformed by Finland in mathematics when taking into account students' problem-solving attitudes. Specifically, openness for problem solving was the best predictor for mathematics achievement. Perseverance also positively predicted mathematics achievement, although less so than openness for problem solving.

Table 7. Hierarchical linear regression coefficients for the Math dependent variable

Model		Unstandardized Coefficients		Standardized Coefficients	*t*	*Sig.*
		B	***SE***	***Beta***		
1	Intercept	524.584	2.178		240.87	.000
	Country	3.098	2.360	.013	1.31	.189
	Gender	-2.675	3.103	-.016	-.86	.389
	Country*Gender	-10.012	3.359	-.059	-2.98	.003
2	Intercept	524.462	1.951		268.85	.000
	Country	-6.719	2.118	-.028	-3.172	.002
	Gender	5.073	2.781	.030	1.824	.068
	Country*Gender	-9.389	3.009	-.055	-3.121	.002
	Perseverance	3.782	.640	.044	5.911	.000
	Openness for Problem Solving	35.075	.625	.423	56.09	.000

Science Achievement

The hierarchical regression analysis indicates that the regression model only comprising the demographic variables (e.g., country, gender, and the interaction between country and gender) employed to predict science literacy (Model 1) is significant [$F(3,19754) = 73.183$, $p < .001$], but it explains a very small proportion of the variance in science scores (Adjusted R^2 = .011). Results show that Country, Gender, and their interaction are significant predictors of science, as shown in Table 8 (Model 1). The results indicate that Finnish students significantly outperform Canadian students. Moreover, females significantly outperform males in science. Additionally, as in the case of mathematics, the interaction between country and gender was significant, indicating that Canadian females are significantly outperformed by all other groups (Canadian males, as well as Finnish females and males) in science achievement, corroborated by Table 6.

The model comprising both the demographic variables and the problem-solving attitudes (Model 2) is also significant [$F(5,19752) = 795.197$, $p < .001$] and it explains a significant proportion of the variance in science scores (Adjusted R^2 = .17). This large difference in the Adjusted R^2 values between models indicates that the problem-solving attitudes play a crucial role in students' science achievement, above and beyond the demographic factors (country, gender, and the interaction between country and gender). Moreover, adding problem-solving attitudes to the model significantly increases the model's capacity to predict science, as well as the percentage of explained variance in science scores by 16%. The interaction between country and gender remains significant in Model 2. When openness for problem solving and perseverance are added to the model, Country, Gender, and the interaction between Country and Gender remain significant in Model 2, as shown in Table 7. This finding indicates that Finland outperforms Canada, females significantly outperform males in science, and Canadian females are significantly outperformed by all other groups considered in the analyses, even after taking into account students' problem-solving attitudes. As in our analyses pertaining to mathematics achievement, the same pattern of results emerged for science achievement: openness for problem solving and perseverance significantly predicted science scores, as shown in Table 8, with openness for problem solving being the best predictor for science achievement.

Table 8. Hierarchical linear regression coefficients for the Science dependent variable

Model		Unstandardized Coefficients		Standardized Coefficients	*t*	*Sig.*
		B	***SE***	***Beta***		
1	Intercept	545.051	2.227		244.73	.000
	Country	-15.152	2.414	-.062	-6.28	.000
	Gender	11.418	3.174	.066	3.60	.000
	Country*Gender	-17.021	3.435	-.098	-4.955	.000
2	Intercept	544.852	2.044		266.58	.000
	Country	-24.169	2.219	-.100	-10.89	.000
	Gender	18.511	2.914	.108	6.352	.000
	Country*Gender	-16.563	3.152	-.095	-5.254	.000
	Perseverance	4.765	.670	.054	7.11	.000
	Openness for Problem Solving	31.277	.655	.368	47.74	.000

Discussion, Limitations, and Future Work

Mathematics

Results show that students' attitudes towards problem solving positively predicted mathematics achievement, above and beyond demographic factors, such as country and gender. Additionally, Canadian females were outperformed by both Finnish female and male students in mathematics, although the former self-reported significantly higher perseverance and openness for problem solving than both Finnish males and females (see Table 5). Moreover, Canadian females were significantly outperformed by Canadian males in mathematics and in self-reported perseverance and openness for problem solving (see Table 5). This finding has implications for instructors who can attend more closely to students' problem-solving attitudes as alternative pathways towards improving student achievement, given the strong relation revealed between attitudes, especially openness for problem solving, and mathematics. For instance, mathematics instructors could encourage students to develop a positive *mathematical mindset* (Boaler, 2015) and they could teach students, especially female students, strategies to develop positive attitudes towards problem solving that decrease mathematical anxiety and increase mathematical achievement. Perhaps improving Finnish and Canadian females' self-reported attitudes towards problem solving with respect to those of their male counterparts (Table 5) will decrease the achievement gap in mathematics between females and males in these countries (Table 6). These types of strategies are more malleable than cognitive skills, with implications for designing interventions that can be integrated into teaching practices, even within an existing curriculum. However, these results prompt further research to untangle the inconsistent relation between academic achievement in mathematics, gender, country, and students' problem-solving attitudes. A different set of factors not considered in our models could drive Finnish females to outperform Canadian females in mathematics, despite their lower self-reported problem-solving attitudes compared to those reported by Canadian females.

Science

Results show that students' attitudes towards problem solving positively predicted science achievement, above and beyond demographic factors, such as country and gender. As in the case of mathematics, Canadian females were significantly outperformed by Canadian males in both science and self-reported problem-solving attitudes. Also, Canadian females were significantly outperformed by both Finnish females and males, although the former self-reported significantly higher perseverance and openness for problem solving than both Finnish males and females (Table 5). Finnish students significantly outperformed Canadian students in science literacy, although they self-reported significantly lower perseverance and openness for problem solving than their Canadian counterparts. Finally, female students outperformed male students in science, despite females' significantly lower self-reported perseverance and openness for problem solving. This result echoes similar findings regarding self-assessment and science achievement (Ehrlinger & Dunning, 2003). Further research is needed to understand the factors that affect differentially the relation between achievement in science and mathematics, gender, country, and problem-solving attitudes.

Limitations and Future Work

One of the limitations of this study is the use of a limited number of items included in the PISA assessment surveying students' attitudes towards problem solving. There may be other indicators more in tune with students' attitudes towards problem solving that could be explored. For example, the gender of the teacher or the type of instruction (lecture-based versus inquiry-based) may be important factors in mathematics and science classes.

An alternative explanation for these results could be the role that other factors play in academic achievement. For example, it was found that ICT use explained the achievement gap in mathematics and science between individuals and schools for Turkish students in PISA 2009 (Delen & Bulut, 2011). Moreover, the PISA 2006 data revealed that students' achievement in mathematics was positively associated with self-reliance in performing ICT Internet tasks, such as browsing the Internet or emailing (Ziya, Doğan, & Kelecioğlu, 2010) and with confidence in performing ICT activities in general (Güzeller & Ayça, 2014). More research needs to be conducted to examine the differences between ICT in mathematics and science instruction and their effect on problem-solving attitudes.

Given the well-documented acute gender divide in STEM areas (Olson & Riordan, 2012), especially in computer science (Zweben & Bizot, 2015), the next step is to test whether the two attitude measures (perseverance and openness for problem solving) are differentially important to females' and males' test performance in other academic subjects. In the near future, we will also explore the role of gender and attitudes towards problem solving (e.g., openness for problem solving and perseverance) in predicting the problem-solving scores generated by the *Creative Problem Solving* assessment that PISA administered for the first time in 2012 as a computer-based assessment (OECD, 2014). We will also examine whether the effects found in Canada and Finland can be generalized to other higher-performing and lower-performing participating OECD and partner countries. Finally, we will examine factors that may promote improved problem-solving strategies and academic achievement.

Conclusions

This study examining the PISA 2012 data of students from Canada and Finland found that students' attitudes toward problem solving positively predicted both mathematics and science achievement. It revealed that Canadian females were significantly outperformed in both mathematics and science by Canadian males, Finnish females, and Finnish males. Moreover, females outperformed males and Finnish students outperformed Canadian students in science. These results will contribute to a growing literature on gender differences as predictors of achievement in STEM. They will also inform recommendations towards teaching attitudes as a way to narrow the gender achievement gap. This study has implications for helping instructors become more aware of the important roles that students' gender and attitudes towards problem solving play in academic achievement. Thus, instructors can adapt their teaching, choose materials that offer equitable academic outcomes, and develop better gender-neutral problem-solving strategies for all students.

Acknowledgements

We are grateful to the University of Alberta Faculty of Education *Support for the Advancement of Scholarship* Grant # G018000473 and the *Killam Research* Grant # RES0032227 for their generous support. We also thank Dr. Rauno Parilla for his insightful comments and the anonymous reviewers for their valuable suggestions that improved this manuscript.

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