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FIRST CYCLE OF PISA (2000–2006)—INTERNATIONAL PERSPECTIVES ON SUCCESSES AND CHALLENGES: RESEARCH AND POLICY DIRECTIONS

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ABSTRACT. This special edition of IJMSE focuses on the Programme of International Student Assessment (PISA) project now that it has completed a full cycle of administration—reading, mathematics, and science—to look at ways in which PISA has been used in participating countries and with what consequences, and to identify potential research and policy directions emanating from this initiative. Articles were invited to (a) reflect international perspectives on the uses and consequences of PISA to date and (b) speculate on future directions for research, curriculum, and policy using the PISA datasets. The introductory article provides a brief overview of common aspects of PISA: Evolving definitions of reading literacy, mathematics literacy, and science literacy; technical design of the instruments and data analysis procedures; the changing emphasis of administrations; and recent research using the datasets. PISA, unlike other international assessments in reading, mathematics, and science, has provided a fresh perspective on 'what might be' by decoupling the assessment from mandated curricula to focus on literacies needed for a 21st century economy. This unique feature of PISA brings with it possibilities and cautions for policy makers.

KEY WORDS: contemporary literacies, hierarchical linear modelling, policy directions, Programme of International Student Assessment (PISA), secondary analyses, technical aspects

This special issue attempts to illustrate patterns emerging from a second sober look and secondary analysis of the Programme of International Student Assessment (PISA) datasets from 2000, 2003, and 2006 (the first full cycle of the assessment) to:

- reveal patterns and potential relationships within and between countries.
- capitalise on the coordinated datasets involving reading literacy, mathematics literacy, and science literacy and other socioeconomic and sociocultural data.
- illustrate policy and decision-making potentials and examples.
- provide descriptions of innovative approaches to the analyses of these complex datasets.
- establish a platform to support future research with PISA datasets and informed policy use of the results including the 2009, 2012, and 2015 results.

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PISA is an international, standardised assessment of 15-year-old students' performance in the literacies of mathematics, science, and reading that was created by the Organisation for Economic Co-operation and Development (OECD) in 1997 to evaluate the achievement of students nearing the end of their public school careers. PISA is administered to all 30 OECD countries and a growing number of non-OECD countries volunteering to participate. For the 2009 administration, the start of the second full cycle of assessments, 67 countries participated.

PISA uses the term *literacy* to encompass a broad range of competencies relevant to coping with adult life (Table 1). These competencies were based on the relevance and applicability to adult life with no specific linkage to curricula of the participating countries. The assessment focuses on young people's ability to apply their knowledge and skills to real-life problems and situations and is administered in a cyclic 3-year schedule, which began in 2000 with a focus on reading with lesser consideration of the other two domains, followed in 2003 with a focus on mathematics and in 2006 with a focus on science. The PISA surveys made an important departure from other international evaluations (e.g. the International Association for the Evaluation of Educational Achievement studies: Trends in International Mathematics and Science Study/TIMSS) by decoupling the instruments from school curricula. PISA's assessment instruments were based on holistic definitions of discipline-specific literacies—those adult skills that will be needed to function in a 21st century economy. This departure broke with the tradition of curriculum-driven surveys and removed the necessity to use the 'lowest common denominator' that requires curriculum coverage of all participating countries in the development and selection of test items. Rather, the assessment was designed to investigate 'what might be' and to document how well young adults are prepared to meet the challenges of their future: to analyse, reason, and communicate their ideas effectively and to have the capacity to continue learning throughout life (OECD, 1999).

PISA also collects information about student background, perceptions, and attitudes and about school traits from school administrators. This results in a substantial pool of information linking mathematics, science, and reading performance to student, home, and school traits that has considerable potential for secondary data analysis with relevance to educational research and policy (Anderson, Lin, Treagust, Ross & Yore, 2007). The resulting datasets of the PISA administrations are made available to researchers on the OECD/PISA website (www.pisa.oecd.org).

PISA was designed to provide policy-relevant information on student performance in the core literacies of reading, mathematics, and science—key elements of the human capital of the knowledge economy. The information generated consists of estimates of student achievement and information about student traits and perceptions as well as school characteristics from the perspective of school administrators, which could be correlated to student performance in reading, mathematics, and science. The OECD states that the knowledge and skills associated with these domains are "necessary for successful adaptation to a changing world" (OECD, 2003, p. 9).

The OECD describes PISA as a collaboration of the participating countries with shared policy-driven interests (OECD, 1999). The OECD administers the program while recognising national sovereignty with each country taking responsibility at the policy level; it stated, "the primary reason for developing and conducting this large-scale international assessment is to provide empirically grounded information which will inform policy decisions" (OECD, 1999, p. 7). The OECD clearly states that the results from PISA allow for international comparisons of student performance, which is the most common result reported, and that the results should lead to enhanced focus and motivation for educational reform and improvement.

The basic sample units for PISA are countries; within each country, students are randomly sampled within schools—with a target of between 5,000 and 10,000 students from at least 150 schools within each country (OECD, 2003). However, actual samples range widely from about 3,500 to over 30,000 students in some countries. The sampling procedure constrains analysis to country-level approaches and within-country school comparisons since it is not possible to conduct analysis at the classroom level (OECD, 2005). In order to generate unbiased estimates of country parameters, sampling weights are determined; replicate weights are provided to allow for the calculation of unbiased standard error estimates of all country parameters.

The concept of literacy used by PISA is "the capacity of students to apply knowledge and skills in key subject areas and to analyse, reason and communicate effectively as they pose, solve and interpret problems in a variety of situations" (OECD, 2003, p. 13). The domains assessed by PISA are defined in slightly different ways across the years (Table 1). The assessment frameworks and the test items provided specificity and emphasis to these broad definitions for the specific administration: 2000—reading, 2003—mathematics, and 2006—science.

The test items used in PISA consist of an approximately even split of multiple-choice and constructed-response items. Sample items for the

TABLE 1

PISA definitions of mathematics, science, and reading literacy

Year	*Mathematics*	*Science*	*Reading*
1999	Being able to reason quantitatively and to represent relationships or dependencies is more important than the ability to answer familiar textbook questions when it comes to deploying mathematical skills in everyday life.	Having specific knowledge, such as the names of specific plants and animals, is of less value than an understanding of broad concepts and topics such as energy consumption, biodiversity, and human health in thinking about the issues of science under debate in the adult community.	The capacity to develop interpretations of written material and to reflect on the content and qualities of text are central skills.
2000	The capacity to identify, to understand, and to engage in mathematics and make well-founded judgments about the role that mathematics plays, as needed for an individual's current and future private life, occupational life, social life with peers and relatives, and life as a constructive, concerned, and reflective citizen.	The capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.	Understanding, using, and reflecting on written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society.

2003	An individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments, and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned, and reflective citizen.	The capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.	An individual's capacity to understand, use, and reflect on written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society.
2006	An individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments, and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned, and reflective citizen.	An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.	An individual's capacity to understand, use, and reflect on written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society.

OECD, 1999, 2000, 2003, 2006

various domains and different levels of proficiency are provided in PISA documentation, which are available for download on the OECD/PISA website. The test booklets consist of items and tasks that students are given 2 h to complete. Tests are derived from a larger pool of items (total testing time of 7 h) that represents the domain of performance in the literacies of mathematics, science, and reading. The test each student completes consists of two-thirds of items for the domain of focus. It should be noted that each student has performance estimates for all domains; the focus domain (e.g. mathematics for PISA 2003) is based on the majority of the test items and the so-called minor domains (e.g. all non-mathematics domains for PISA 2003) are based on small numbers of test items. In order to provide estimates of student performance, a 1-parameter item response theory (IRT) model analysis was used to generate student scores. The performance estimates are scaled to have a mean of 500 with a standard deviation of 100 for the OECD countries. The use of item response modeling approaches to scoring and analysis generates error estimates that are specific to different locations across the distribution of ability scores, unlike classical test analysis and scoring that generate a single standard error estimate for all scores generated by a test. The focus on assessment quality within this IRT approach is on accurate estimates of error (hence the use of replicate sampling weights to address sampling error and plausible values to address measurement error) for individual scores and for country-level parameters (means, percentages, correlations, and regression coefficients). The generation of these standard error estimates provides an index of consistency of the ability estimates and country-level parameters and allows for meaningful comparison of values between countries. For a more complete description of these measurement issues, the reader is referred to the technical manuals produced for each PISA administration (e.g. OECD, 2005).

In addition to assessing student cognitive proficiency, PISA collects information about student attitudes, perceptions, and background. These student variables and indices include gender, grade and level of courses taken in school, home resource indices, home traits (parents' education and employment), self-regulated cognition, student motivation and engagement, emotional factors, and perceptions of school traits. Information about schools (e.g. instructional processes and school organization) is obtained from a questionnaire that school principals complete. Variables documented by the school questionnaire include instructional practices, school organization, school decision making, school resources, school climate, and teacher and school autonomy.

The design and development of the PISA datasets lead to analytic approaches that are very attentive to accurate estimates of student performance and of the magnitude of error associated with each parameter estimated. The datasets were specifically developed with replicate sampling weights to better estimate country parameters and plausible values of student performance scores for unbiased estimates of student literacy levels at the country level. These features routinely result in replicate analyses of over 400 and, with the inevitable missing data associated with multivariate analysis, sometimes over 2,000 replications of computation within a given analysis. This cumbersome and at times daunting analysis requires a relatively steep learning curve to begin the engagement with the PISA datasets as well as substantial run-times that many analysts may not have experienced in contemporary computing. However, this analytic approach is well supported by a detailed technical manual and the statistical subroutines (macros) developed by OECD for both SAS and SPSS. These are freely available for download on the OECD/PISA website along with the data and reports.

It should be noted that PISA does not explicitly recognise and elaborate the role of languages (natural and mathematical) in identifying questions, constructing or acquiring new knowledge, crafting explanations, and making evidence-based claims using argumentation. Nor does PISA explicitly recognise language and cultural dependencies in the public debate about science-technology-society-environment (STSE) or socioscientific issues resulting in informed decisions and sustainable actions (Sadler & Zeidler, 2009). Science educators are quick to recognise inquiry as a fundamental attribute of science; however, few recognise the essential nature of language, especially written language and argumentation in doing science (Yore, Pimm & Tuan, 2007). Language is used not only to report knowledge claims but also to shape those claims and explanations. However, the simultaneous assessment of reading, mathematics, and science literacies allows consideration of the literacy component of mathematical literacy and scientific literacy not explicit in the assessment frameworks. Table 2 provides the student-level correlations amongst the literacies measured by PISA 2000, 2003, and 2006. These relatively strong correlations between literacy scores across the literacy domains suggest that the PISA measures of literacies tend to target student attributes that are common across the three domains of mathematics, science, and reading. These associations (61–77% shared variance) should not be considered as causal relationships, but they cannot be disregarded totally in the light that similar associations in large-scale testing programs are in the 0.35–0.45 range (12–20% shared variance).

The main reports generated from each PISA administration include an ordered-by-country listing of performance scores on each of the assessed literacies—the so-called league tables—which constitute the most widely

TABLE 2

Correlations of reading literacy, mathematics literacy, and science literacy from PISA 2000, 2003, and 2006

	PISA assessment		
Domains	*2000*	*2003*	*2006*
Reading—Mathematics	0.80	0.78	0.80
Reading—Science	0.85	0.82	0.85
Mathematics—Science	0.88	0.82	0.88

communicated information from the PISA administrations. However, the reports are much more comprehensive in that they include chapters describing the nature of PISA and its instrumentation and chapters on more nuanced analyses such as relationships of traits associated with student learning (e.g. motivation, cognitive strategies, socioeconomic status), school traits (e.g. school climate, assessment practices, school size and organization) to level of student performance.

Some Recent Research

The Correlates of Leaning Outcomes (COLO) project of the Centres of Research in Youth, Science Teaching and Learning (CRYSTAL) Pacific funded by the Natural Sciences and Engineering Research Council, Canada have used these datasets to explore national and international relationships, models and comparisons of mathematical and scientific literacies, and various student, school, country, and culture attributes (Anderson, Milford & Ross, 2009). Gu (2006) examined and compared the relationships among students' self-beliefs in mathematics, learning environment at school, and mathematics achievement at student and school levels in Canada and Hong Kong-China. Hierarchical linear modeling (HLM) of the PISA 2003 data revealed that school learning environment has more effect on school mathematics achievement in Hong Kong than in Canada. The Canada model has stronger relationships between students' self-beliefs in mathematics and their mathematics performance than the Hong Kong model. School variations of self-efficacy and self-concept effects are accountable by school learning environment in Hong Kong but not in Canada. Hsu (2007) investigated and compared the effects of student characteristics (i.e. socioeconomic status, gender, family structure, and immigration background) on mathematics achievement in Canada and Hong Kong. The HLM results showed that schools in Canada and Hong Kong accounted for 20% and 49% of the variance in mathematics achievement, respectively. All student-level variables except family structure were significant in the Canada model whereas only gender and immigration background were significant in the Hong Kong model. At school level, the significant school aggregate variables had much larger effects on school average mathematics achievement in Hong Kong than in Canada. The findings suggest that school composition has an effect on mathematics achievement over and above that of individual student characteristics.

Ram (2007) investigated the effects of student- and school-level variables on mathematics achievement in Canada and Japan using the PISA 2003 data and HLM. The student-level variables used in this analysis included student gender, perceived teacher support, and socioeconomic status (SES); the school-level variables included principals' perceptions of both student and teacher morale and commitment, and student- and teacher-related factors affecting school climate. The results revealed that the proportion of variance in mathematics scores attributable to schools was 20% in Canada and 54% in Japan. In both countries, higher ratings by principals on both student commitment and morale and student-related factors affecting school climate were linked to higher mathematics achievement.

Ross (2008) explored the relationship between achievement motivation and academic achievement in two distinct cultures: Western (Canada, the United States, and the United Kingdom) and Asian (Hong Kong-China, Japan, and Korea). HLM was used to analyse PISA 2003 data to model each country for the outcomes measures of each literacy domain. The variables examined at the student level were instrumental and intrinsic motivation, performance orientation, and self-efficacy. The variables examined at the school level were teacher support, student morale, and teacher behaviours affecting school climate. In the null models, the intraclass correlations for the Western countries were consistently lower (0.17–0.27) than for the Asian countries (0.36–0.53). In the final HLM models, at level-1, intrinsic motivation predicted an increase in scores for all of the Asian country models, but results were inconsistent for the Western country models. However, instrumental motivation predicted an increase in scores in seven of the Western country models but was not significant in any of the Asian country models. Performance orientation predicted a decrease in scores in all of the Western country models and in seven of the 12 Asian country models. Self-efficacy predicted increased scores for all models for all countries. At level-2, teacher support was significant in the models for Japan only. Results for teacher behaviours were inconsistent. Student morale was significant in all models for all countries. The findings from this study demonstrate that there are some distinct cultural differences in the relationships between achievement motivation and academic achievement.

OECD (2007a; 2007b) reported some interesting phenomena about student performance in Asian countries/economies on PISA 2006. Chinese Taipei, Hong Kong, Japan, and Korea are highlighted here because they were among the top 11 countries/economies (Liechtenstein and Korea had the same science scores of 522) and, where appropriate, contrasted against the top-performing country, Finland. First, Korean students scored higher than the OECD average on Physical and Earth and Space systems but scored 30% lower than average on Living system. Hong Kong students scored higher than the OECD average on Living system but scored lower than average on Earth and Space system. Chinese Taipei students scored lower than the OECD average on Earth and Space system.

Second, among these four countries/economies, Chinese Taipei students scored 10+ points higher in explaining phenomena scientifically than overall in science while Korean students scored 10+ points higher in science overall than in explaining phenomena scientifically. Korean students demonstrated relative strength in using scientific evidence, which was higher than explaining phenomena scientifically. Compared to the other Asian countries/economies, Chinese Taipei students scored 10+ points higher, on average, for questions requiring knowledge of science. However, developing abilities in explaining phenomena scientifically and in using scientific evidence appears to need attention.

Third, inconsistent results were found in the relation between student performance and self-efficacy in science among these four countries/economies. The results revealed that fewer students in Japan and Korea with higher mean performance in science reported high self-efficacy in science. However, more students in Hong Kong and Chinese Taipei with higher mean performance in science reported high self-efficacy in science. Similar results were also found in student performance in science and awareness of environment. Even with the inconsistent results among these four countries/economies, over 90% of students in Korea, Hong Kong, and Chinese Taipei reported that they agreed with the statement ‘advances in science and technology usually bring social benefits’.

Fourth, gender differences in attitudes toward science in Chinese Taipei, Hong Kong, Japan, and Korea were identified with males reporting more positive attitudes than the females. However, this is not the case in Finnish schools where no gender differences were found and the standard deviation was found to be smaller than in other OECD countries (Lavonen & Laaksonen, 2009).

Fifth, these four countries/economies had above-average levels of student performance in science and below-average impact of socioeconomic background on science performance. However, Chinese Taipei results revealed that the strength of the relationship between performance and socioeconomic background was not statistically significantly different from the OECD average. The results for Hong Kong, Japan, and Korea revealed that their strength of the relationship between performance and socioeconomic background were significantly below the OECD average impact.

Sixth, the results revealed that Japan (53%) had the highest total between-school variance among the four Asian countries/economies, followed by Chinese Taipei (45.8%), Hong Kong (34.1%), and Korea (31.8%) compared to Finland (4.7%) and the OECD average (33%). Inspection of the within-school variance revealed that Japan (59.4%) was the highest among the four countries/economies followed by Chinese Taipei (51.7%), Korea (59.3%), and Hong Kong (58.3%) compared to Finland (76.7%) and the OECD average (68.1%).

Finally, the results revealed that the percentage of students agreeing or strongly agreeing with the five questions about index of instrumental motivation to learn science for Japan and Korea were all below the OECD average while Chinese Taipei and Hong Kong were all above the OECD average. Surprisingly, the results showed that the students in these four Asian countries/economies had a higher mean performance in science but a smaller proportion of students expected to be in a science-related career at age 30 (OECD, 2007a).

These results revealed that the four Asian countries/economies with similar high-risk entrance examinations and similar high parental and school expectations shared some commonalities about student characteristics in performance (gender and attitudes toward science), but their science curricula appear to emphasise different competences investigated in the PISA assessment framework (e.g. Chinese Taipei was good at explaining phenomena scientifically and knowledge of science but not at using scientific evidence). The results might provide insights for policy makers about educational reform and implementation. Lavonen & Laaksonen (2009) stated, "The most important reasons for success [of Finnish students' performance in PISA 2006] are successful implementation of education policy cornerstones, *knowledge based society,* *educational equality* and *devolution of decision power at the local level*, through curriculum policy, teacher education, local level decision-making and science teaching approaches in the science classroom." (p. 939).

Milford (2009) broadened COLO's investigation of the relationships between science self-beliefs and academic achievement in science across all nations who participated in PISA 2006 and explored the variance accounted for by cultural, social, and economic capital (ESCS, the elements of the PISA SES variable) for each country when predicting scientific literacy. Further, using HLM he modeled data for nations experiencing high rates of immigration (i.e. Germany, Spain, Canada, the United States, Australia, and New Zealand) using achievement scores in science, mathematics, and reading. The variables examined at the student level were science self-efficacy, science self-concept, immigrant status, and socioeconomic status. The variables examined at the school level were student-level aggregates of school proportion of immigrants and school socioeconomic status. In the correlation analysis between science literacy and either science self-concept or science self-efficacy, findings suggest that at the student level students with both higher science self-concept and higher science self-efficacy tended to achieve higher academically. However, at the country level the relationship was negative between self-concept and academic achievement in science. When the variables that comprised each component of ESCS were regressed on scientific literacy for the PISA sample, cultural capital accounted for 16% of the variance in scientific literacy scores compared to 14% for social capital, 13% for the composite ESCS, and 12% for economic capital. In the HLM null models, the intraclass correlations for all countries, except Germany, ranged from .16 to .29 (Germany's was between .57 and .68). In the final models, at level-1 country, immigrant status tended to negatively influence achievement (i.e. non-native students are predicted to have lower performance) while science self-efficacy and science self-concept positively influenced achievement. The student-level ESCS variable was also positively related to achievement. At the school level, both mean ESCS and proportion of immigrants were found to significantly influence the level-1 predictors; however, a good deal of variability across nations was observed. The findings demonstrated that there are some distinct national differences in the relationships between science self-belief, immigrant status, and academic achievement.

The results from the COLO project and those reported in a recent special issue of the *Journal of Research in Science Teaching* (Bybee, Fensham & Laurie, 2009) reveal the range of scholarship flowing from primary and secondary considerations of the PISA datasets and results.

These second sober looks and analyses identify the uses, abuses, consequences, research potentials, and policy directions arising from post hoc deliberations and the preparations for future assessments and opportunities of the second full cycle of administrations (PISA 2009, 2012, 2015).

The Articles in This Special Issue

The articles in this special issue report on PISA-related research and reforms from the Americas, Asia, Australia, and Europe. The authors utilised a variety of designs and analysis techniques (historical case studies, document analysis, HLM, correlations, multinomial modeling, regression analysis) to provide evidence for their claims. Each study provides a part of the mosaic that more clearly describes the advantages and disadvantages of large-scale international assessments and comparisons and the unique contributions of PISA 2000, 2003, and 2006. The final article integrates these studies and their results to reveal insights into educational policy and decision making, a frequently neglected area of mathematics and science education research (Fensham, 2009).

Closing Remarks

PISA has broken the tradition of curriculum-based international assessments to explore an extra-curricular approach of 'what might be' and to provide data, results, and insights for negotiating future mathematics and science education reforms and policies. Many researchers, policy makers, and other stakeholders did not fully understand this underlying framework; many others did not and do not accept the definitions of reading literacy, mathematics literacy, and science literacy and the associated assessment frameworks. The contributions in this special issue will help people to better understand the second full cycle of PISA, to be prepared to avoid misinterpretations and abuses, and to capitalise on the windows of opportunity provided by PISA 2009, 2012, and 2015. Some articles in this special issue might even inform the modifications and interpretations of PISA 2010 (mathematics) and PISA 2015 (science).

We are hopeful that the operational definitions of mathematical literacy and scientific literacy will be revised to more explicitly reflect the language/literacy components of these disciplinary literacies (Moje, 2008; Norris & Phillips, 2003; Shanahan & Shanahan, 2008; Yore et al., 2007). These constructs have worldwide interest and cachet but, more importantly, they have potential in explaining and enhancing mathematics and science understanding and application in real-life situations. The variations in models across countries demonstrate that there is no grand model that fits all. Three pathways of impact have been revealed in this special issue:

- The immediate, policy-driven, large-scale reform in reaction to relatively low standing on summary reports (the league-tables effect); for example, the Germany and Denmark articles.
- The research-driven, fine-grained approaches to developing national models to better understand the functioning of student learning and school performance; for example, the Japan, Hong Kong, Australia, Ireland, Czech Republic, and Belgium articles.
- The regional comparison approach in which groups of participating countries with shared contextual features and connections are considered to explicate school effectiveness and academic achievement; for example, the Americas article.

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