INQUIRY-BASED, TEACHER-DIRECTED AND ADAPTIVE INSTRUCTION IN SECONDARY SCIENCE: A CROSS-NATIONAL ANALYSIS OF ASSOCIATIONS WITH SCIENCE LITERACY AND INTEREST USING PISA 2015

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Abstract

This paper reports our ongoing investigation of relationships between learning and teaching in science classrooms, and students' science literacy and interest in science. Our investigation of these relationships uses secondary analysis of Programme for International Student Assessment (PISA) data that in 2015 had science as its focus. Consistent with our analysis of PISA 2006, this study shows that increases in the frequency of inquiry-based teaching in science is *negatively* associated with students' science literacy. For students in six Anglophone countries (Australia, Canada, Ireland, New Zealand, the UK and the USA), the more frequently students experience inquiry-based teaching, the weaker their literacy in science, on average. The study also showed moderately strong positive associations between teacher-directed and adaptive instruction, and students' science literacy. Our analysis further revealed a modest positive association between all three pedagogies examined and students' enjoyment of science. This was consistent for all six countries, and slightly stronger for female students, on average. Notable across several countries is the considerably less positive enjoyment of science baseline shown by females in comparison to their male counterparts. It appears that an affective domain gender gap remains favouring boys. This would seem to call for further research, likely of a qualitative nature to better understand girls' enjoyment in science and how it might be bolstered. Last, it is equally notable that for all six countries, and for both females and males, adaptive instruction seems to consistently demonstrate the strongest positive association with enjoyment in science, and with students' science literacy. At a minimum, the findings reported here call for renewed examination and discussion of how competing instructional approaches might be best conceived and applied in helping students learn and like science.

Note: This paper is based on, in part, and extends, a manuscript currently under review at a science education research journal, and a paper proposal accepted but not presented at the 2018 annual meeting of the World Educational Research Association (WERA) in Cape Town, South Africa, 3-5 August, 2018

Keywords: Science literacy, enjoyment of science, Inquiry-based teaching in science, teacher-directed teaching, adaptive instruction, PISA, secondary analysis, science teacher education.

1 INTRODUCTION

In science education research and policy, the availability of large-scale, high-quality international assessment data—like Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA)—has allowed scaled-up examination of associations between various pedagogical approaches, such as inquiry-based teaching and learning, and students' science literacy and engagement in science [1], [2], [3].

In this study, we report research that builds on previous investigations of inquiry-based teaching in science that used PISA 2006 [2]. Our previous investigation found that for Australia, Canada and New Zealand, students who reported high levels of inquiry also showed above-average levels of interest in science, but below-average levels of science literacy. We also found the corollary to be true. These findings ran counter to orthodox views about the effectiveness of inquiry-based teaching in science. In the current study, using data from the most recent PISA (2015), we extend our analysis to include teacher-directed and adaptive instructional approaches in science for six countries, Australia (AUS), Canada (CAN), Ireland (IRL), New Zealand (NZL), the United Kingdom (UK) and the United States of America (USA). In the study, we ask two research questions:

Research Question 1: To what extent is the variability observed in science literacy (as measured in PISA 2015) associated with the frequencies of three distinct approaches to teaching and learning science, reported by students from their science classrooms? To what extent does this vary by country and/or gender?

Research Question 2: To what extent is the variability in students' interest in science associated with the frequencies of three distinct approaches to teaching and learning science, as reported by students? To what extent does this vary by country and/or gender?

2 METHODOLOGY

PISA is an international standardised assessment of the literacy of 15-year-old students in reading, mathematics, and science conducted on a 3-year cycle that began in 2000. Each round of PISA assesses all three subjects and focuses in depth on one of the three; in 2015, the focus was science. PISA is intended by the Organisation for Economic Co-operation and Development (OECD) to support development of countries' educational systems toward knowledge and skills necessary for highly developed economies [4], [5]. Rather than assessing students using a particular national or curriculum-based measure, PISA assessments have been intentionally separated from specific national curricula; the assessments are purposely based on descriptions of discipline-specific literacies that refer to "students' capacity to apply knowledge and skills in key subjects, and to analyse, reason and communicate effectively as they identify, interpret and solve problems in a variety of situations" [6 p. 25].

In addition to being assessed on science literacy as defined by PISA's conceptual framework [6], participating students also respond to a short questionnaire about 'themselves, their homes, and their schools and learning experiences' [7]. Several items from the background questionnaire (e.g., parents' education, parents' occupations, number of books and other resources in the home) are combined to form a student-level index representing socioeconomic status, called the index of economic, social and cultural status (ESCS); ESCS is standardised to a mean of zero and a standard deviation of one [6].

Importantly, PISA also includes surveys of teaching and learning strategies experienced by 15 year-olds in their science classrooms. Specifically, PISA asks students how often particular learning/teaching activities happened in their science classrooms. PISA uses these items to create several composite variables, including indices of inquiry-based (IBTEACH), adaptive (ADINST), and teacher-directed (TDTEACH) instruction. The items comprising these indices ask students to indicate on a four-point scale ("in all lessons"; "in most lessons"; "in some lessons"; "never or hardly ever"), the frequency with which they experience various learning and teaching activities. For all indices, higher values indicate that the activities happen more frequently in their science classrooms [8].

This study analyses relationships between students' science literacy and enjoyment of science (including student's *interest in learning about science*), and students' reports on the frequency of various teaching approaches used in their classrooms. To achieve this, we used secondary analysis of PISA 2015 data for Australia (AUS), Canada (CAN), Ireland (IRL), New Zealand (NZL), the United Kingdom (UK) and the United States of America (USA). These six share broadly similar systems of secondary schooling, and similar sociocultural histories of English colonisation and post-colonial development. Also, they share similar levels of socioeconomic development and all are among the top 20 countries on the United Nations Development Programme (UNDP) 2016 Human Development Report's list of very high human development. To answer our research questions, we used descriptive benchmark and correlation analyses, and linear regression via the International Association for the Evaluation of Educational Achievement's (IEA) IDB Analyzer. We examined the direction and relative size of the effect on science literacy and enjoyment of science for each teaching approach, while controlling for the other two approaches.

3 RESULTS

To answer the two research questions asked in this study, we used PISA's three composite variables, representing distinct teaching/learning approaches (IBTEACH, TDTEACH, ADINST), categorical variables such as country, and PISA's composite measure of student socioeconomic status (ESCS) to statistically "level the playing field" across countries. The item components of PISA's three composite variables are given in Table 1.

Table 1. Grouping of ideas about teaching strategies: Students were asked 'How often does this happen in your school science?'

Inquiry-based (IBTEACH)	*Teacher-directed (TDTEACH)*	*Adaptive instruction (ADINST)*
Students are given opportunities to explain their ideas	The teacher explains scientific ideas.	The teacher adapts the lesson to my class needs and knowledge.
Students spend time in the laboratory doing practical experiments.	The teacher explains <school science> idea can be applied	The teacher provides individual help when a student has difficulties
Students are required to argue about science questions.	A whole class discussion takes place with the teacher.	The teacher changes the structure of the lesson on a topic
Students are asked to draw conclusions from an experiment they have conducted.	The teacher discusses our questions.	
The teacher explains how a science idea can be applied to different phenomena	The teacher demonstrates an idea.	
Students are allowed to design their own experiments.		
There is a class debate about investigations		
The teacher clearly explains the relevance of science concepts		
Students are asked to do an investigation to test ideas.		

3.1 Science Literacy

In answering our first research question, and consistent with the OECD's primary analysis of PISA 2015 [6] as well as our previous analysis of PISA 2006 [2], this study's analysis shows that the frequency of inquiry-based teaching (IBTEACH) is negatively associated with students' science literacy. For students in six countries (AUS, CAN, IRL, NZL, GBR and USA), the more frequently students experience inquiry-based activities, the weaker their literacy in science, on average.

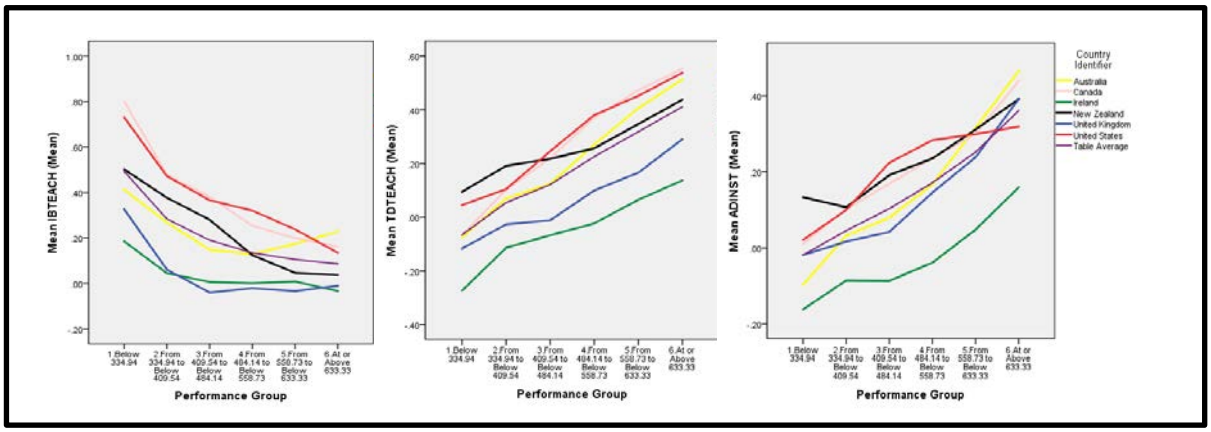

Figure 1. Mean levels of inquiry-based, teacher directed and adaptive instruction in science at six science literacy benchmarks for students in six countries in PISA 2015

In contrast, our analysis also revealed moderately strong positive associations between teacher-directed (TDTEACH) and adaptive instruction (ADINST) and students' literacy in science, consistently for all six countries. These relationships are depicted in Fig. 1. Furthermore, multivariate regression analysis conducted with the IDB Analyzer, and accounting for students' socioeconomic backgrounds, showed that adaptive and teacher-directed instruction were consistently associated with positive effects in students' science literacy whereas inquiry-based teaching was consistently associated with negative effects.

3.2 Enjoyment of science

In answering our second research question and again consistent with the OECD's primary analysis and our previous analysis of PISA 2006 [2], this study shows that the frequency of inquiry-based teaching in science (IBTEACH) is positively, although modestly, associated with students' enjoyment of science. These relationships are shown in Fig. 2.

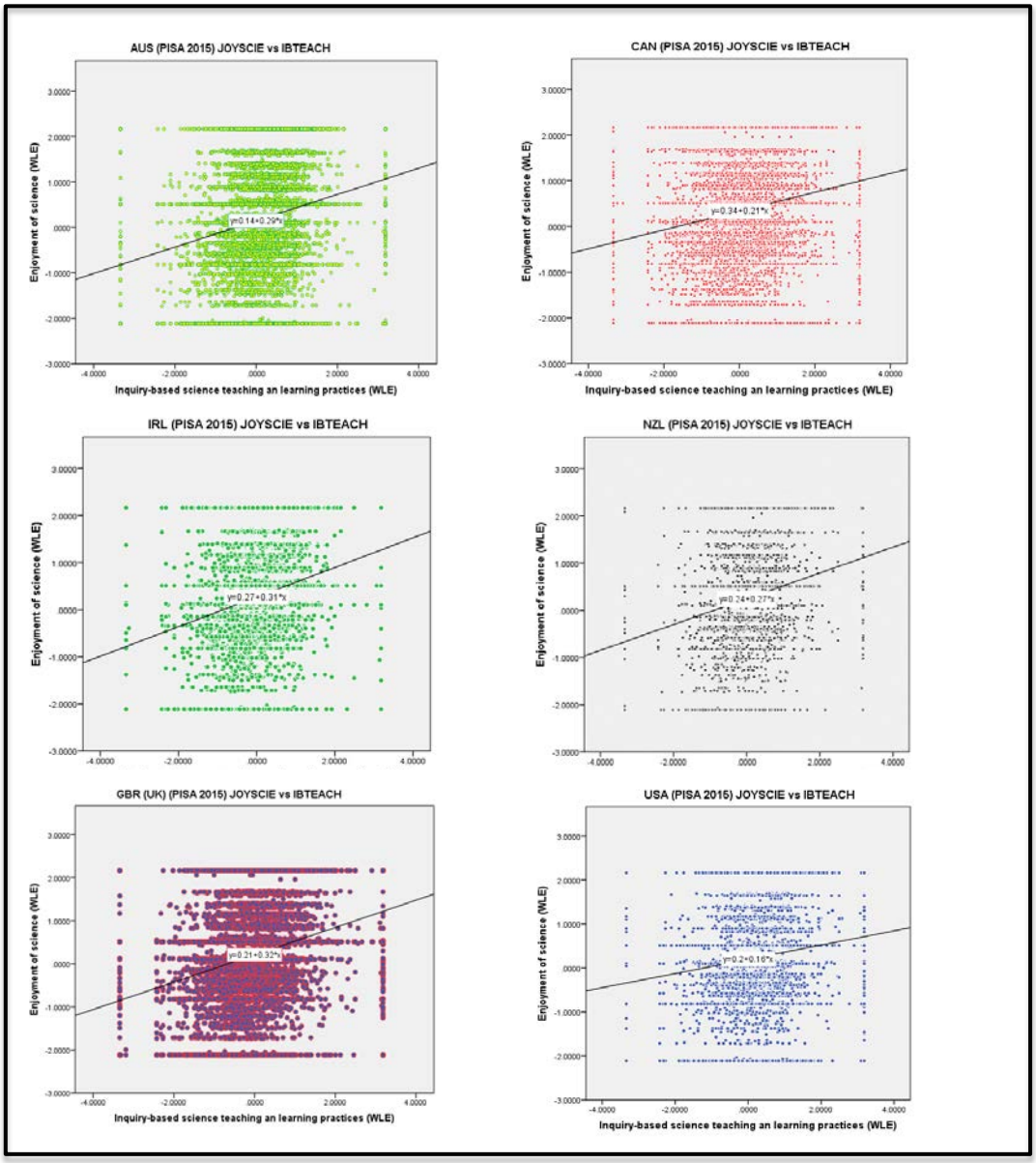

Figure 2. Bivariate scatterplots for inquiry-based teaching in science versus enjoyment of science for students in six countries in PISA 2015.

For students in six countries (AUS, CAN, IRL, NZL, GBR and USA), the more frequently students experience inquiry-based activities, the stronger their enjoyment of science, albeit modestly, on average. This was also consistently the case for the bivariate associations observed in six countries between students' enjoyment of science and the frequency with which they experienced teacher directed and adaptive instruction in their science classes, as shown below in Table 2.

Table 2. Bivariate correlations between students' enjoyment of science and three distinct approaches to teaching science, across six countries in PISA.

	IBTEACH	TDTEACH	ADINST
Australia	0.23	0.30	0.34
Canada	0.17	0.26	0.30
Ireland	0.23	0.26	0.29
New Zealand	0.22	0.29	0.33
United Kingdom	0.26	0.28	0.32
United States	0.16	0.23	0.25

Most importantly, multivariate regression analysis, accounting for students' socioeconomic backgrounds, showed that all three instructional approaches were consistently associated with positive, although mainly modest, effects for both female and male students' enjoyment of science. The coefficients associated with the three instructional approaches are given in Table 3. As can be seen in Table 3, adaptive instruction consistently had the strongest association for both males and females across all six countries. In several of the countries examined, it was also notable that female students had considerably lower baseline levels of enjoyment of science in comparison with their male peers.

Table 3. Multivariate regression coefficients (unstandardized) of students' enjoyment of science and three distinct approaches to teaching science, across six countries in PISA 2015.

	Sex	Number of cases	Constant	ESCS	IBTEACH	TDTEACH	ADINST
Australia	F	5324	-0.01	0.14	0.15	0.13	0.26
	M	5141	0.16	0.16	0.03	0.18	0.30
Canada	F	8824	0.15	0.15	0.05	0.11	0.25
	M	8172	0.26	0.21	0.05	0.15	0.24
Ireland	F	2479	0.22	0.16	0.13	0.10	0.21
	M	2488	0.30	0.18	0.07	0.15	0.23
New Zealand	F	1855	0.11	0.21	0.17	0.16	0.22
	M	1791	0.15	0.13	0.05	0.17	0.27
United Kingdom	F	5868	0.02	0.17	0.15	0.13	0.21
	M	5831	0.18	0.12	0.16	0.13	0.25
United States	F	2504	0.04	0.11	0.09	0.12	0.15
	M	2422	0.24	0.09	0.01	0.13	0.21

4 CONCLUSIONS

With increasing focus on effective, evidence-informed practice in education, our obligation as science teacher educators is to prepare new teachers based on the strongest research evidence available regarding the efficacy of various pedagogical approaches in science. Given the call to arms for educators and educational systems to attend to evidence of effectiveness, therefore, the findings reported in this paper, and in our earlier work [6, 13] call for renewed examination of how inquiry and other pedagogies in science might be best understood and applied in helping students become literate in, and enjoy, science.

4.1 Science Literacy

In answering the first research question, both Fig. 1 and our regression analyses are clear and consistent across the six countries. Teacher directed and adaptive instructional strategies have positive and moderately strong bivariate and multivariate associations with students' science literacy. Inquiry-based teaching, in contrast, has a consistently negative association with students' science literacy. In other work currently under review we have demonstrated that this apparently negative (linear) association may in fact be masking more subtle nonlinear (curvilinear) associations at the level of component items that comprise the composite variable [9], consistent with findings from Norway [3]. Nevertheless, our analysis shows that the conceptualisation and enactment of prominent instructional strategies require ongoing re-evaluation, particularly in the preparation of new teachers.

4.2 Engagement in science

In answering the second research question, Fig. 2 and the regression analyses presented in Table 3 generally show modestly positive associations between the three pedagogical approaches and students' enjoyment of science across the six countries selected. Notable across several countries is the considerably less positive enjoyment of science baseline shown by females in comparison to their male counterparts. Although many OECD countries have in recent years closed the achievement gap in science between girls and boys, it appears nevertheless that an affective domain gap remains favouring boys. This would seem to call for further research, likely of a qualitative nature to better understand girls' enjoyment in science and how it might be bolstered.

Last, it is equally notable that for all six countries, and for both females and males, adaptive instruction seems to consistently demonstrate the strongest positive association with enjoyment in science, in the context of its competitor pedagogies, and accounting for students' socioeconomic circumstances. Given that adaptive instruction also showed consistently positive associations with students' science literacy, it may be wise to be more forthright in advocating for and using this approach.

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