Inquiry, Engagement, and Literacy in Science: A retrospective, cross-national analysis of PISA 2006

Abstract

In this study, we examine patterns of students' literacy and engagement in science associated with different levels of 'inquiry-oriented' learning reported by students in Australia, Canada, and New Zealand. To achieve this we analysed data from the Organisation for Economic Co-operation and Development's (OECD) 2006 Programme for International Student Assessment (PISA) which had science as its focus. Consistently, our findings show that science students who report experiencing *low levels of inquiry-oriented learning activities* are found to have above average levels of science literacy, but below average levels of interest in science, and below average levels on six variables that reflect students' engagement in science. Our findings show that the corollary is also true. Across the three countries, students who report *high levels of inquiry-oriented learning activities* in science are observed to have below average levels of science literacy, but above average levels of interest in learning science, and above average engagement in science. These findings appear to run counter to science education orthodoxy that the more students experience inquiry-oriented teaching and learning, the more likely they are to have stronger science literacy, as well as more positive affect towards science. We discuss the implications of these findings for science educators and researchers.

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For at least five decades, an increasingly conventional wisdom in science education has been that implementing inquiry-oriented teaching and learning promotes higher student achievement in school science. Beginning with authors like Bruner (1961) and Schwab (1962), science education communities have collectively adopted the view that promoting and implementing inquiry-oriented science in the schools encourages higher science achievement, and attitudes toward science (e.g., Bell, Urhahne, Schanze, & Ploetzner, 2010; Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2010; Tamir, Stavi & Ratner, 1998). In short, inquiry-oriented science education is commonly identified as “the method of choice” to improve both interest and achievement in science (PRIMAS, 2011, p. 4) because it is seen as authentically mirroring what scientists do in the real world, and therefore conceptually and pedagogically effective for improving science learning.

Inquiry in school science

From the latter half of the 20th century, science educators have called for school science to be made more relevant for students, by providing “a basis for understanding and coping with their lives…to contribute to general personal and intellectual development” (Black, 1993, pp. 8-9). That is, one often-articulated, keystone purpose of school science is the development of students’ (and society’s) scientific literacy, including students’ ability to reason in a scientific context, engage in scientific inquiry and use scientific habits of mind (NRC, 2012). The promotion and implementation of inquiry-oriented science in the schools became a focus when research indicated that inquiry led to improved science achievement and better appreciation of science compared with pre-1955 traditional textbook-based, didactic approaches (Shymansky, Kyle, & Alport, 1983; Shymansky, Hedges & Woodworth, 1990). Along with the shift to a scientific inquiry approach, the evolution of science in schools has seen the embedding of constructivist approaches to teaching and learning (e.g., Driver & Oldham, 1986). Constructivist principles around learners' active, personal construction of knowledge, for example, resonate well with the consensus that school science should help students understand how scientific ideas are developed and appreciate the usefulness of the skills and processes of scientific inquiry in everyday applications (DfES, in Tweats, 2006). In this vein, Black (1993) noted that school science should entail "learning about the concepts and the methods which are combined in scientific enquiry" (p. 8).

The US National Science Education Standards (NRC 1996; 2012) have underscored the central role of inquiry in achieving the purposes of school science with specific and extensive references to students "describing objects, asking questions, constructing explanations and testing explanations against current scientific knowledge" (NRC, 1996, p. 2). Additionally, a recent synthesis of research on inquiry-based science instruction (Minner, Levy and Century, 2010) highlights the very substantial investments made in countries such as England and Australia to "encourage teachers to use scientific inquiry in their instruction as a means to advance students' understanding of scientific concepts and procedures" (p. 474). For example, the science content of the Australian curriculum includes *Science Inquiry Skills* as one of its three strands and students are "challenged to explore science, its concepts, nature and uses through clearly described inquiry processes" (available at http://www.australiancurriculum.edu.au/science/content-structure).

Unsurprisingly, the research literature in support of inquiry-oriented science is longstanding and considerable (e.g., Lee & Songer, 2003; Shymansky, Hedges & Woodworth, 1990). For example, Rocard (2007) noted that “pedagogical practices based on inquiry-based methods are more effective” (p. 7) and Yip (2011) described the approach as “a teaching strategy that fosters creativity, autonomy, intellectual scepticism, active participation and interaction of students” (p. 114). Similarly, UK Government reports have attributed beneficial effects to inquiry, noting that in “schools which showed clear improvement in science subjects, key factors in promoting students’ engagement, learning and progress were more practical science lessons and the development of the skills of scientific enquiry” (Ofsted, 2011, p. 6).

Despite apparently high degrees of consensus around the centrality and value of inquiry-based approaches, debate continues around the nature of what constitutes inquiry (Barrow, 2006; Minner, et al., 2010) and how this can be best communicated and shared with practicing or pre-service science teachers (Capps & Crawford, 2013). For example, scientific inquiry has been described as including “student-centered interactions, student investigations and hands-on activities, and focus on models or applications in science” (Areepattamannil, 2012, p. 135). From Bybee’s (2006) perspective, however, inquiry is not the same as a “hands-on activity” (p. 1). One framework of inquiry-oriented science education that gives a context to how inquiry is understood by science teachers is a continuum describing *confirmation* inquiry, *structured* inquiry, *guided* inquiry and *open* inquiry (Banchi & Bell, 2008). Confirmation inquiry is used to “reinforce a previously introduced idea” wherein process skills and data collection are undertaken (Banchi & Bell, 2008, p. 26) and will be familiar to many teachers (Furtak et al., 2012, p. 306). In structured inquiry, students are required to “generate explanations” (Banchi & Bell, 2008, p. 26), whereas guided inquiry has students develop their own research methods having been presented with a research question by the teacher. Open inquiry, perhaps the most student-centred approach, is described as imitating scientists as students “develop questions, design and carry out investigations and communicate their results” (Banchi & Bell, 2008, p. 27). Open inquiry also resonates with inquiry-based skills such as students’ ability to ask questions, state hypotheses, process data and reach defensible conclusions (Sadeh & Zion, 2009; Tamir, Friedler, & Nussionwitz, 1982).

Inquiry as enacted in classrooms thus covers a multitude of meanings, ranging from collaborative group work, discovery learning, practical work, specific classroom materials, and the nature of science. The current iteration of the US standards (NRC, 2012) emphasises the complexity and ambiguity that can be associated with an inquiry approach because inquiry “has been interpreted over time in many different ways throughout the science education community” (p. 30). However, the emphasis on a student-centered approach is clear with the expectation that

> …students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves. (p. 30)

Furthermore, in this study we determine inquiry to incorporate those practices in which “students may be responsible for naming the scientific question under investigation, designing investigations to research their questions and interpreting findings from investigations” a description provided in a recent Campbell Collaboration systematic review (Nadelson, William & Turner, 2011, p. 1).

In addition to various interpretations around what constitutes inquiry in school science, there is also a wide variety of practical suggestions for improving inquiry advanced by researchers as benefiting students’ thinking (Cleaves & Toplis, 2007) including embedding inquiry throughout the curriculum, extending time for investigations, and increasing the use of information and communications technology (ICT). At the same time, there remains a lack of clear distinction in many school curricula between developing students' practical skills, such as data collecting, manipulating apparatus, or working like a scientist, and students' cognitive development fostered through questioning, evidence-based explanations and developing arguments. Similarly, the relationship between students' scientific investigative skills and understanding the nature of science is often not clear-cut. Students may be able to demonstrate proficiency in scientific investigative skills, where for example, the need for repeated measurement can be stated (and thus the student assessed to be competent) without drawing on subject matter knowledge to support scientific claims made (Kind, 2003).

Linking the two domains of 'practical work' and 'ideas' in science, Abrahams and Millar (2008) argued that "one does not simply 'emerge' from the other" (p. 1966) and that teachers' skills at scaffolding enables better learning. In support of this, research shows that more experienced teachers who had been enriched with science learning experiences in university and as part of their professional development, also showed greater use of inquiry in their classrooms (Brown, et al., 2006; Capps & Crawford, 2013). In a recent meta-analysis, Furtak et al. (2012) reported that teacher-guided inquiry appears to be more effective in supporting student learning than student-led or traditional lessons. Further, the largest effects on student learning were evident in studies where the key cognitive component of inquiry was epistemic which, in contrast to procedural, social or conceptual foci, meant students "being able to examine and evaluate the quality of evidence and then develop explanations for phenomena" (Furtak et al., 2012, p. 305). These findings appear consistent and supportive of those reported by the *Inquiry Synthesis Project* (Minner et al., 2010) which concluded that, across 138 studies there was

> …a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques. (p. 474)

Questions around inquiry in school science

Recent research, however, raises questions about the association between science achievement and inquiry-oriented science teaching and learning. For example, one review of teacher-directed and student-directed approaches to learning (Chall, 2000) concluded that teacher-directed approaches, in general, led to higher academic achievement than more student-focused approaches. Similarly, and more specifically in science, multilevel analysis of Programme for International Student Assessment (PISA) data for Qatari adolescents who experienced inquiry-oriented teaching and learning strategies in their science classrooms found high interest in science but below average levels of science achievement for these students. These apparently counterintuitive results were attributed to low levels of reading, literacy and numeracy skills (Areepattamannil, 2012).

Similar results have been reported for Canadian (Areepattamannil, Freeman & Klinger, 2011) and Finnish adolescents (Lavonen & Laaksonen, 2009). In both of these studies, the prevalence of investigation activities in science classes were revealed as a “strong negative predictor of science performance” (Areepattamannil, 2012, p. 142). These results suggested that “a combination of traditional teacher-delivered instruction and the conducting of practical work by students results in higher academic performance than more student-directed learning, such as inquiry” (Lavonen & Laaksonen, 2009, p. 937). Additionally, a recent study in the Los Angeles

Unified School District investigated science inquiry professional development for teachers using a large-scale three-year randomised controlled trial (RCT). Contrary to what might be expected based on current views around the efficacy of inquiry for science learning, Grigg, Kelly, Gamoran and Borman (2013) found that during the first year of the trial students in the fourth grade (Year 4) who experienced inquiry in their science classes performed less well on district wide science assessments compared with their counterparts who did not experience inquiry.

Together, these studies suggest the need for science education research communities to revisit widely held assumptions and advocacy for inquiry-oriented approaches in school science. Although broad consensus seems to exist in science education communities around the central purpose of science education in the schools (scientific literacy), an often implicit assumption has been that students who experience high levels of inquiry-oriented teaching and learning in school science would also achieve well (demonstrate high literacy) and be positively engaged (have positive affect) in science.

Our purpose in this study, therefore, is to examine the extent to which students who describe their high school science classes as highly inquiry-oriented could also be characterised as having higher than average levels of science literacy and/or higher than average levels of engagement in science. In other words, we examined the common assumption that if students are frequently involved in inquiry-oriented science learning activities, they will do better in science. To investigate this assertion, we used student data from PISA 2006 for Aotearoa New Zealand, Australia, and Canada. We intentionally chose these three member countries of the Organisation for Economic Co-operation and Development (OECD) because they share similar socio-cultural roots and systems of secondary education, and all have consistently performed strongly in science on international comparative assessments like PISA.

Specifically, the questions we posed for this retrospective analysis are:

1. To what extent do 15-year-old students—in Australia, Canada and New Zealand—report experiencing high levels of inquiry oriented learning activities in their science classes? Conversely, to what extent do students in these countries report low levels of inquiry learning activities in science?
2. For 15-year-old students who report high levels of inquiry learning activities in science, what levels or patterns of science literacy and/or engagement in science are discernible? If evident, to what extent are these consistent across three countries with similar education systems and socio-cultural histories?
3. Similarly, what levels or patterns of science literacy and/or engagement in science are discernible for 15-year-old students who report low levels of inquiry learning activities in their science classrooms? If evident, to what extent are these consistent across the three countries in this study?

Method

As described above, in modern science education a widely held view is that students who experience higher levels of inquiry-oriented learning in science would also be those who perform well on measures of science achievement and engagement. Our purpose in this study, therefore, is to empirically examine the notion that the extent to which students experience inquiry-oriented teaching and learning activities would be associated with differing levels of performance and engagement in science. To achieve this purpose we used retrospective (secondary) analysis of extant PISA 2006 datasets for Australia, New Zealand, and Canada, retrieved online from the Australian Council for Educational Research (http://pisa2006.acer.edu.au/downloads.php).

PISA is an international standardized assessment of the literacy performance 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 also focuses in considerable depth on one of the three, which in 2006 was science. The next round intended to focus on science is scheduled for 2015. The OECD’s underlying intent for PISA is to support further development of participating countries’ educational systems toward the knowledge and skills necessary for globally-facing, highly-developed economies (OECD 2004, 2007). To meet this intent, PISA surveys have been intentionally decoupled from specific school or country curricula; rather, the assessments are purposely based on more holistic descriptions of discipline-specific literacies.

For New Zealand, the 2006 PISA dataset included 170 schools and 4,823 students; Australia’s sample included 356 schools and 14,216 students; and, Canada’s comprised 896 schools and 22,646 students. These three countries were intentionally chosen because of strong commonalties in socio-cultural histories and traditions (e.g., all three are parliamentary democracies, with histories of British colonial rule, and are members of the Commonwealth). Additionally, all three countries have systems of comprehensive, state-supported secondary schooling, and have been perennially high performers on PISA. In 2006, for example, only Finland and Hong Kong-China outperformed Canada and New Zealand, and Australia was a close third (not statistically different from New Zealand) in science performance. In PISA 2009, among 65 countries, Australia, Canada, and New Zealand tied for second in science performance, behind Shanghai-China, Finland, Hong Kong-China, Singapore, Japan, and Korea (Knighton, Brochu, & Gluszynski, 2010).

In choosing within-country participants, PISA uses a two-stage sampling frame by which schools are first sampled and then students sampled within participating schools. This means that sampling weights are associated with each student because students and schools in any particular country may not have the same probability of selection, and some groups are over-sampled to allow national reporting priorities to be met (OECD, 2009). This type of sampling has the potential to increase the standard errors of population estimates. In this study therefore, and consistent with PISA's recommendation, all statistics have been produced using a Balanced Repeated Replication (BRR) procedure with 80 replication estimates to generate unbiased standard errors that take account of clustering in the samples (OECD, 2009).

In addition to assessing science literacy as defined by PISA's conceptual frameworks, students also respond to a short questionnaire about their background details (family, home life), science classroom experiences, and a broad suite of affective variables (self-concept, self-efficacy, enjoyment of science, interest in science, valuing of science, motivations with regard science, etc.).To achieve our purpose in identifying those students in each country who experienced high and low levels of inquiry-based learning activities in their science subjects, we used students' responses to Question 34 on PISA's Student Questionnaire which asks students to rate how frequently they experience 17 classroom strategies for learning science. Prompted by **"***when learning <school science> topics at school, how often do the following activities occur?***"** students respond on a scale ranging from "In all lessons" (1) to "Never or hardly ever" (4).

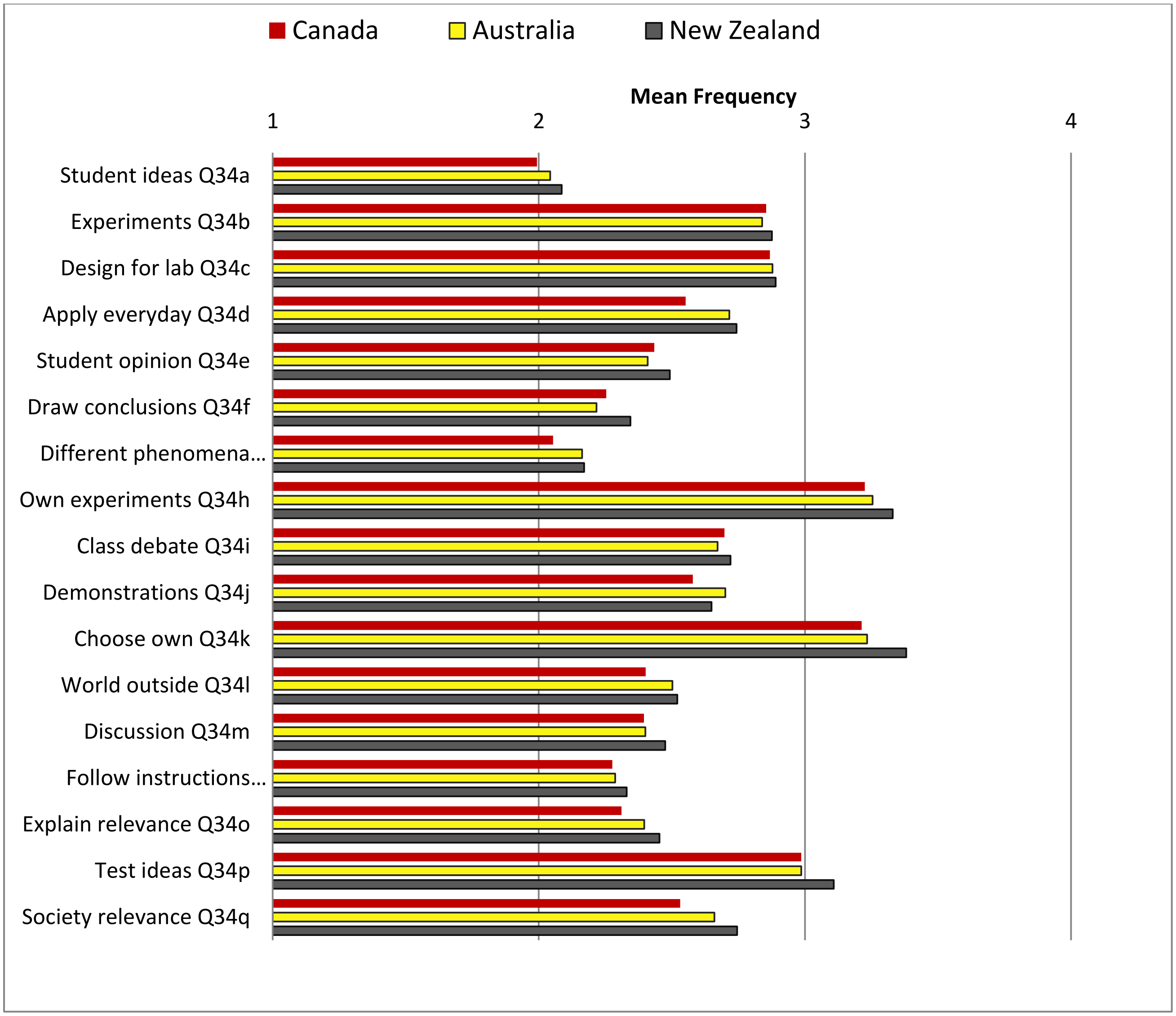
To identify student-reported levels of inquiry, each member of our research team (five science educators, each with many years of experience teaching science and science education) independently selected those items from Question 34 that best reflect inquiry-oriented learning activities in secondary science. Individual selections were compiled and through iterative discussion, consensus reached that 6 of the 17 items in Question 34 best reflected our team's understanding of what is commonly meant by an inquiry-based approach to learning and teaching in science. These items included:

Q34a) Students are given opportunities to explain their ideas
Q34c) Students are required to design how a <school science> question could be investigated in the laboratory
Q34f) Students are asked to draw conclusions from an experiment they have conducted
Q34h) Students are allowed to design their own experiments
Q34k) Students are given the chance to choose their own investigations
Q34p) Students are asked to do an investigation to test out their own ideas

Four of these six items (Q34a, f, h and p) had previously been used in the PRIMAS (2011) study that compared European teachers' reports of their inquiry-based teaching with PISA data, suggesting that these items were useful in indicating students' perception of inquiry-oriented activities in science classes.

To examine whether the six items that our research team identified measured a common construct, we used factor analysis of the 17 Question 34 items, for each of the three countries included. Using Principal Components Analysis as the extraction method, and Varimax rotation, factor analysis showed that 4 of the 6 items (Q34c, h, k and p) loaded consistently and strongly (loadings ranged from 0.480 to 0.793) on a common factor. In only one case (Q34c for Canada) was any item's loading shared with a second factor. Further, 3 of the 4 items (Q34h, k and p) were grouped by PISA to represent a construct PISA termed "student investigations." On the other hand, two items our team had initially identified as reflective of inquiry-oriented learning in science (Q34a and f) consistently loaded on separate factors for all three countries. PISA had grouped Q34a) with 3 other items as a reflection of student-teacher "interaction" in science classrooms, and Q34f) with 3 other items to reflect the extent of "hands-on" activities. Given the PRIMAS (2011) research experience, however, along with Minner et al.'s (2010) research synthesis indicating that inquiry is comprised of *both* students' thinking and drawing conclusions *and* active engagement in scientific investigations, we ultimately decided to include all 6 items to reflect the prevalence of inquiry-oriented learning activities in science classrooms.

We emphasise that in PISA students are not asked to report on inquiry-based learning and teaching *per se*. Rather, as indicated by the 6 example items provided above, (Q34a, c, f, h, k, p) students are asked to report on the frequency with which they experience distinct learning activities in their science classes. This lowers the need for inference making on students' part, and heightens the likelihood that students' self-reports of learning activities accurately reflect the situation in their classes. In support of this view, PISA also reported good reliability (internal consistency) for its science teaching and learning items (Q34), with Cronbach's alpha ranging between 0.70 and 0.81 across the three countries. Additional evidence for the trustworthiness of students' reports is offered in Figure 1 which portrays Q34 item means for 22 thousand Canadian high school students, 14 thousand Australians, and nearly five thousand New Zealanders.



Note. Scale = 1 "In all lessons" to 4 "Never or hardly ever"

Figure 1. Mean Levels of Science Learning Activities Reported by Students across Three Countries.

At risk of stating the obvious, students in PISA do not communicate with or know each other, other than students within a school. The high consistency of patterns of student responses seen in Figure 1 suggests that if students are misrepresenting the frequency of learning activities they experience in their classrooms, they are doing so in a remarkably (impossibly) consistent manner across three countries!

To be able to identify those students who typically reported experiencing clearly high or low levels of inquiry-oriented learning activities, the six Q34 items were transformed into a composite variable. Using this "level of inquiry in learning science at school" variable, two groups of students were selected from each country's dataset: 1) those students who reported experiencing *low levels of inquiry*, which we defined as those whose "level of inquiry in learning science at school" was more than 1 standard deviation (SD) above the overall mean for that country[1]; 2) those students who reported experiencing *high levels of inquiry*, which we defined as students whose "level of inquiry in learning science at school" was more than 1 standard deviation (SD) below the mean for that country. Table 1 provides the number and proportion of each country's students that via this method, we classified as experiencing either "low inquiry" or "high inquiry" science learning activities in school.

Additionally, we conducted descriptive analyses of science literacy performance and interest in learning science using comparisons across six student groups organized by country and level of inquiry in science (low or high). To achieve these analyses we used the BRR procedure (Fay variant) with 80 replication estimates and 5 plausible values for science literacy and interest in science, respectively, to construct means and standard errors, in keeping with guidelines provided by PISA (OECD, 2009).

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[1] Question 34 of PISA's Student Questionnaire uses a response scale for which higher numbers mean a lower frequency of occurrence (4 = "never or hardly ever") and lower numbers indicate a higher frequency of occurrence (1="in all lessons").

Table 1. Proportions of students in Australia, Canada, and New Zealand who experienced low and high levels of inquiry in science learning, in PISA 2006.

PISA 2006	Low Inquiry Focus			High Inquiry Focus		
	AUS	CAN	NZ	AUS	CAN	NZ
Average level of inquiry in learning science (1 = In all lessons; 4 = Never or hardly ever)	3.51	3.64	3.64	1.90	1.74	1.90
Number of students	2191	2447	603	2018	2640	538
Proportion of students	18%	14%	14%	17%	15%	12%

In addition to group-wise comparisons of science literacy performance and interest in learning science, we also comparatively examined students' levels of engagement in science for the six groups (three countries, two levels of inquiry in school science). To accomplish this we computed the means for each of the groups on a suite of six variables, measured by PISA's Student Questionnaire that we previously argued reflect a comprehensive, multi-dimensional measure of students' engagement in science (Authors, 2013a; 2013b). These six "engagement in science" variables include students' general interest in science; enjoyment of science; personal and general valuing of science; science self-efficacy; and science self-concept. Specifically, PISA's index of *enjoyment of science* is derived from students' level of agreement with statements like *I generally have fun when I am learning science topics* and *I am happy doing science problems* on a four-point scale with response categories "strongly agree", "agree", "disagree" and "strongly disagree". PISA's index of *personal value of science* reflects students' level of agreement with statements like: *I will use science in many ways when I am an adult*; and, *science is very relevant to me*. Similarly, PISA's measure of *general value of science* reflects levels of agreement with statements like: *advances in science and technology usually improve people's living conditions*; and, *science is valuable to society* (OECD, 2007).

PISA's index of *self-efficacy in science* assess students' beliefs in their ability to accomplish science-related tasks on their own (for example, their ability to recognise a science question underlying a report predicting how changes to an environment will affect the survival of certain species) using a four-point scale with the response categories: *I could do this easily*, *I could do this with a bit of effort*, *I would struggle to do this on my own* and *I couldn't do this*. Similarly, *self-concept in science* is derived from students' level of agreement with statements like: *learning advanced science topics would be easy for me*; *I learn science topics quickly*; and, *I can easily understand new ideas in science*. In PISA, student responses to each of these engagement in science variables have been inverted for scaling with positive values indicating higher levels of general interest, enjoyment, personal and general valuing, self-efficacy, and self-concept in science (OECD, 2007). All variables have been standardized to a mean of zero and a standard deviation of 1 (OECD, 2007).

Findings

In this study we used retrospective analysis of PISA 2006 data to examine longstanding, strong assumptions about associations among the frequency with which high school science students experience inquiry-oriented learning strategies, students' literacy performance and interest in learning science, and students' affective responses (engagement) towards science, across three similarly developed countries. Using a composite variable constructed from responses to the PISA Student Questionnaire we first identified students who clearly reported either low or high levels of inquiry in their science classrooms. As shown above in Table 1, this variable allowed clear differentiation between high and low inquiry groups of students. In answer to research question 1, relatively similar proportions of 15-year-old students in Australia, New Zealand, and Canada reported experiencing high levels of inquiry-oriented learning activities in science (12% to 17%). Similarly, at the low end of the continuum, relatively comparable proportions of students (14% to 18%) reported experiencing infrequent levels of inquiry-oriented learning activities, across the three countries.

The relatively modest proportions of students in Australia, Canada and New Zealand reporting high frequencies of inquiry-oriented learning activities in science is perhaps less than surprising. A European report *What do we know about 'inquiry' learning in science classrooms?* (Rocard, 2007) noted that although there is agreement in science education communities that inquiry-based pedagogical methods are more effective "the reality of classroom practice is that in the majority of European countries, these methods are simply not being implemented" (p. 3). This is echoed in Australia, where, based on an empirical study of science classrooms, Goodrum (2006) noted

> the importance of inquiry has resonated through Australian science education circles for the past 40 years…[so] one would expect to see inquiry as an integral part of our secondary science classrooms…[but] traditional didactic teaching methods that offer little challenge, excitement or opportunities for engagement are common. There is a considerable gap between the intended curriculum as described in the various curriculum documents and the actual curriculum experienced by students. (p. 31)

The national government has responded, in part, by funding a national science curriculum initiative, *Science by Doing* (http://www.science.org.au/sciencebydoing/) under the auspices of the Australian Academy of Science. The initiative has developed what are described as 'inquiry-based curriculum units' as a way to increase the likelihood of 'inquiry' being implemented. Similar situations can be found in New Zealand where according to the Education Review Office (2012) 'high quality examples of successfully integrating science into inquiry-based teaching and learning were limited' and Canada, where the national government has funded curriculum materials to promote 'inquiry' (http://galileo.org/classroom-examples/classroom-examples-high-school-science/).

In answer to research question 2, and similarly organized according to students' perceptions of the extent to which they experienced inquiry-oriented learning strategies in their science classrooms, Table 2 provides average scores in science literacy performance and interest in learning science as measured in PISA, and average scores for the suite of six engagement in science variables. Figure 2 portrays these descriptive statistics for students' literacy performance and content specific interest in learning science, organized by students' perceived levels of inquiry in their science classrooms, and by students' home country.

Both Table 2 and Figure 2 show that in all three countries, students who report experiencing *high levels of inquiry* oriented strategies in their science classrooms were observed to have levels of science literacy performance, on average, considerably below their respective country averages. For example, students in New Zealand who reported high levels of inquiry in science performed on average 37 score points below their country average. (Typically, across OECD countries participating in PISA, about 40 score points equate to one year of schooling (OECD, 2010; 2013).

Table 2. Science Literacy and Engagement for Australia, Canada, and New Zealand, by Level of Inquiry in Learning Science, using PISA 2006.

	Low Inquiry			High Inquiry		
Measures (PISA 2006)	**AUS** n = 2191	**CAN** n = 2447	**NZ** n = 603	**AUS** n = 2018	**CAN** n = 2640	**NZ** n = 538
Level of inquiry in science learning (1 = In all lessons; 4 = Never or hardly ever)	3.51	3.64	3.64	1.90	1.74	1.90
Science literacy[a]	531	551	534	512	505	493
Interest in learning science [b]	441	450	428	492	496	504
General interest in science	-0.53	-0.15	-0.47	0.08	0.37	0.29
Enjoyment of science	-0.34	-0.04	-0.37	0.20	0.38	0.36
Personal value of science	-0.27	-0.07	-0.28	0.40	0.53	0.46
General value of science	-0.26	-0.07	-0.38	0.20	0.34	0.07
Science self-efficacy	-0.09	0.08	-0.28	0.41	0.41	0.21
Science self-concept	-0.39	-0.02	-0.50	0.25	0.61	0.32

[a] Overall country means in science literacy for Australia, Canada and New Zealand are 527, 534, and 530, respectively.
[b] Overall country means for interest in learning science for Australia, Canada and New Zealand are 465, 469, and 461, respectively.

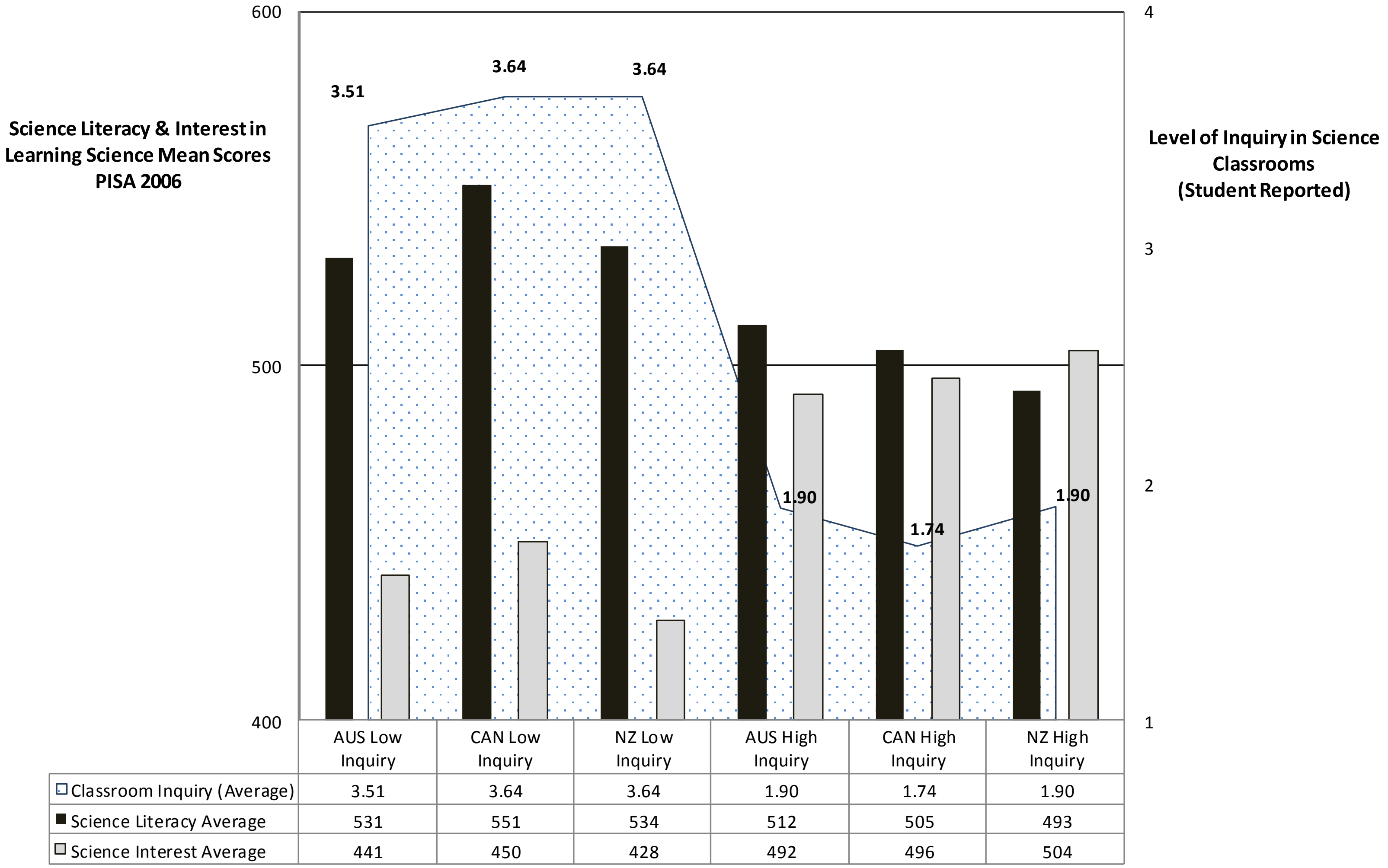
On the other hand, and for all three countries, students who reported experiencing high levels of inquiry in their science classrooms also had above average levels of interest in learning science and more positive than average responses on PISA variables measuring general interest in science, enjoyment of science, personal and general valuing of science, self-efficacy and self-concept in science, as portrayed in Figures 2 and 3. For example, students in Australia who reported high levels of inquiry also had, on average, interest in learning science 27 points above the Australian mean.

Research question 3 addressed patterns of literacy performance, interest in learning science, and engagement in science for students reporting *low levels of inquiry* strategies in their science classrooms. In answering this research question, Table 2 and Figures 2 and 3 show that in all three countries, students who report experiencing low levels of inquiry oriented strategies in their science classrooms were observed to also have levels of science literacy, on average, above their respective country averages. For example, students in Canada who reported low levels of inquiry in their science classrooms performed on average 17 score points above their country's average. Furthermore, for all three countries, students who reported experiencing low levels of inquiry in science also had below average levels of interest in learning science and more negative than average general interest in science, enjoyment of science, personal and general valuing of science, self-efficacy and self-concept in science, as shown in Figures 2 and 3. For example, students in Australia who reported low levels of inquiry in their science classes also had interest in learning science on average 24 points below their country average, and self-reported enjoyment of science less positive than the Australian mean. Additionally, Table 3 provides mean differences and standard errors (SE) between high and low inquiry groups in science literacy, interest in learning science, and engagement in science for Australia, Canada, and New Zealand.

Table 3. Mean Differences between High and Low Inquiry Groups in Science Literacy, Interest in Learning Science and Engagement in Science for Australia, Canada, and New Zealand.

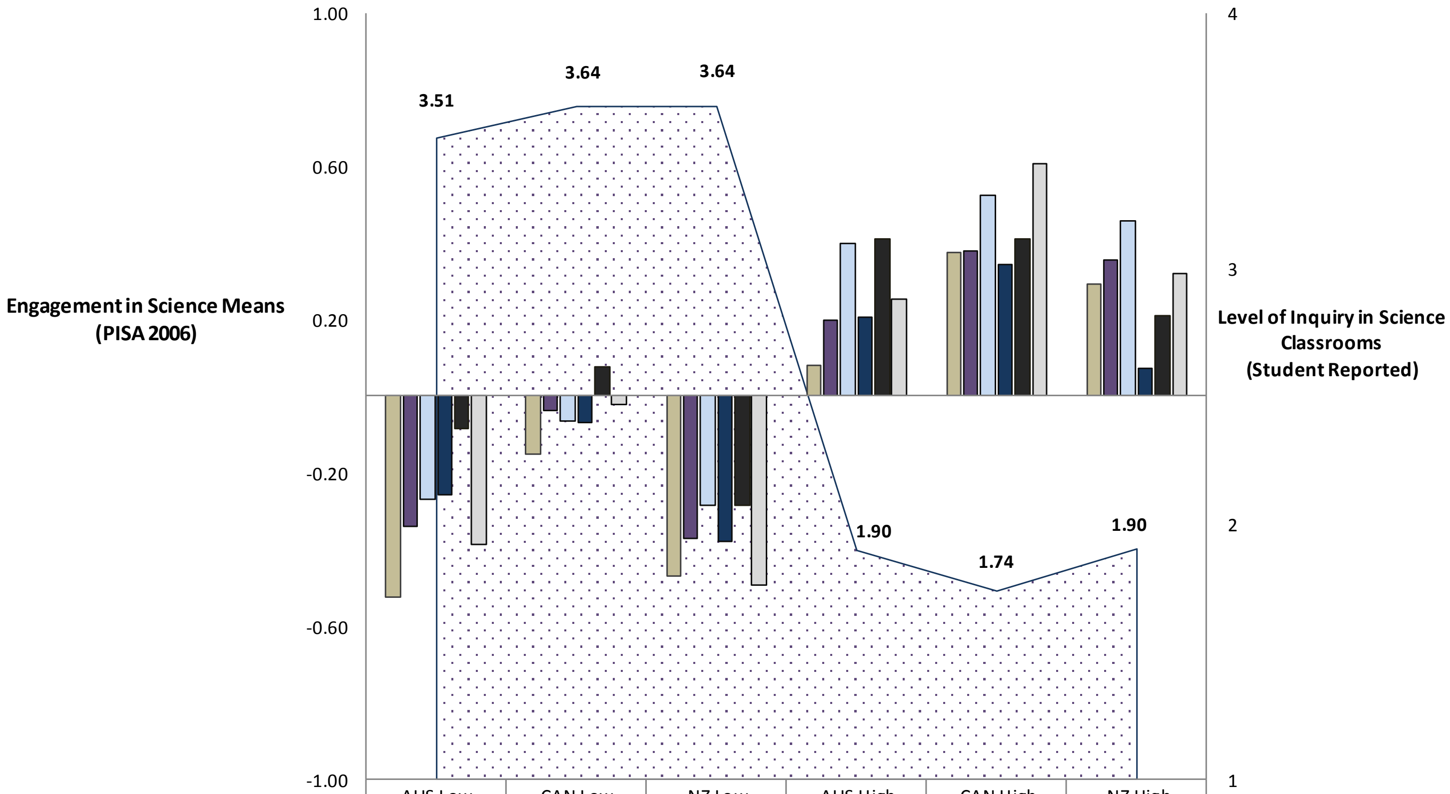
	Australia		Canada		New Zealand	
	Mean diff.	SE diff.	Mean diff.	SE diff.	Mean diff.	SE diff.
Science literacy	-19^	5.17	-47	5.73	-41	7.80
Interest in learning science	51	4.17	46	5.51	76	6.11
General interest	0.60	0.05	0.53	0.04	0.76	0.07
Enjoyment	0.54	0.04	0.42	0.05	0.73	0.07
Personal value	0.67	0.05	0.59	0.06	0.74	0.07
General value	0.46	0.04	0.41	0.05	0.46	0.07
Self-efficacy	0.50	0.04	0.33	0.06	0.49	0.07
Self-concept	0.64	0.04	0.63	0.05	0.81	0.07

* $p < 0.0001$; ^ $p = 0.0002$



	AUS Low Inquiry	CAN Low Inquiry	NZ Low Inquiry	AUS High Inquiry	CAN High Inquiry	NZ High Inquiry
□ Classroom Inquiry (Average)	3.51	3.64	3.64	1.90	1.74	1.90
■ Science Literacy Average	531	551	534	512	505	493
□ Science Interest Average	441	450	428	492	496	504

Figure 2. Average Levels of Science Literacy and Interest for Students Reporting High and Low Levels of Inquiry in Science Teaching, across Three Countries.



	AUS Low Inquiry	CAN Low Inquiry	NZ Low Inquiry	AUS High Inquiry	CAN High Inquiry	NZ High Inquiry
☐ Classroom Inquiry (Average)	3.51	3.64	3.64	1.90	1.74	1.90
■ General interest	-0.53	-0.15	-0.47	0.08	0.37	0.29
■ Enjoyment	-0.34	-0.04	-0.37	0.20	0.38	0.36
☐ Personal value	-0.27	-0.07	-0.28	0.40	0.53	0.46
■ General value	-0.26	-0.07	-0.38	0.20	0.34	0.07
■ Self-efficacy	-0.09	0.08	-0.28	0.41	0.41	0.21
☐ Self-concept	-0.39	-0.02	-0.50	0.25	0.61	0.32

Figure 3. Average Levels of Engagement in Science for Students Reporting High and Low Levels of Inquiry in Science Teaching, across Three Countries.

In every case, these differences were found to be statistically significant. For science literacy performance, mean differences favoured students who reported experiencing low levels of inquiry-oriented learning activities in their science classes. In contrast, for subject-specific interest in learning science and for the six variables measuring students' engagement in science, the mean differences shown in Table 3 universally favoured students who reported high levels of inquiry-oriented learning activities in their science classes. In summary, the patterns evident among: a) the frequency with which high school students report experiencing inquiry oriented learning strategies in science; b) students' literacy performance in science; and, c) students' affective engagement in science, appear both clear and consistent across 3 similarly developed countries. For Australian, Canadian and New Zealander students, those who report experiencing low levels of inquiry oriented learning in their science classrooms, are those also observed to have above average levels of science literacy in comparison to their respective country averages. Additionally, across the three countries, students who reported experiencing low levels of inquiry in their science classrooms also had more negative than average levels of subject-specific and general interest, enjoyment, valuing, self-efficacy and self-concept in science. The corollary was also found to be true. Australian, Canadian and New Zealander students participating in PISA, who reported high levels of inquiry oriented strategies in science, were observed to have levels of science literacy below their respective country averages, but more positive than average levels of interest, enjoyment, valuing, self-efficacy and self-concept in science compared to their within-country peers.

Discussion and conclusion

The findings evident from this secondary analysis of PISA 2006 data across three similar OECD countries initially puzzled us. For many years it has been generally accepted that, at least in science, the extent to which teachers pursued the recommended approach of using inquiry strategies and involving students in scientific investigation as scientists do, would result in concomitant levels of scientific understanding. As noted by Lederman, Lederman and Antink (2013) "current wisdom advocates that students best learn science through an inquiry-oriented teaching approach. It is believed that students will best learn scientific concepts by doing science…" (pp. 142-143). Our analysis of 2006 PISA data, however, suggests that this is not always the case. In PISA, students who reported experiencing higher levels of science inquiry are those who have lower than average levels of scientific literacy but above average levels on variables representing affective engagement in science. Thus, although these findings support the view that students who experience more inquiry learning in science are also more positively engaged towards science they do not support the hypothesis that higher levels of inquiry in science classrooms are accompanied by higher levels of science literacy, and call into question the robustness of the view that higher levels of achievement are mediated by positive affect in science. In other words, the results of more than 40,000 students across three high-performing countries appear to run counter to the conventional wisdom that the more students experience an inquiry-oriented approach to teaching and learning science, the more likely they are to achieve higher levels of scientific literacy because the more positive they are towards science.

These seemingly paradoxical results are even more unexpected in the context of PISA's formulation of science literacy performance. PISA has emphasised that its cognitive survey questions have been deliberately decoupled from specific school or country curricula and are instead based on holistic descriptions of discipline-specific *literacies*. Specifically, PISA describes its view of scientific literacy as

> …scientific knowledge and use of that knowledge to identify questions, acquire new knowledge, to explain scientific phenomena and to draw evidence-based conclusions about science related issues; their understanding of the characteristic features of science as a form of human knowledge and enquiry; their awareness of how science and technology shape our material, intellectual and cultural environments; and their willingness to engage with science-related issues, and with the ideas of science, as a reflective citizen (ACER, 2013, p. 7)

It would therefore seem reasonable to expect that students who experience substantial inquiry would also have above average science literacy since they have experienced science learning in ways that align well with the intent of PISA. Instead, in this retrospective analysis we observe that students who report higher than average levels of inquiry type learning are indeed more positive about science than their peers, but achieve less well on PISA's measure of science literacy. Although it is possible that students who consistently experience inquiry could in the future become not only more engaged, but also more scientifically literate, the association between positive engagement and higher literacy performance in science for students characterised as experiencing high-inquiry science is not supported by these findings. These results underscore the need for longitudinal studies to better understand relationships among inquiry-oriented learning and teaching, engagement in science, and scientific literacy, and how these develop for students across time.

Another issue that could provide some insight into this study's results is associated with the inherent characteristics of an inquiry-oriented approach to teaching and learning science. By its very nature the inquiry cycle does not easily afford the time or space to address the full breadth of content often called for by secondary school science (Harlen, 2010). Instead, inquiry typically emphasises depth of understanding and development of ideas that mimic scientists' deep understanding of specific questions or topics. If students are assessed with instruments that measure the breadth of their science knowledge, they may not fare well if they have experienced teaching strategies oriented toward more in-depth understanding of a limited number of topics. It is possible that PISA's assessment of science literacy performance misses the mark for students experiencing high levels of inquiry, which would likely mean substantial depth but restricted breadth. This study's findings may therefore suggest further study of PISA's cognitive items to examine the extent to which the assessment aligns with inquiry-oriented science currently advocated by the science education community.

Whilst initially paradoxical, our findings in this secondary analysis are not isolated. As noted previously, research that calls into question the association between science achievement and inquiry-oriented science has been reported in studies of Qatari high school students (Areepattamannil, 2012), Canadian high school students (Areepattamannil, Freeman & Klinger, 2011), Finnish adolescents (Lavonen & Laaksonen, 2009), and fourth grade students in the US (Grigg, et al., 2013). If we acknowledge, as suggested by more recent studies, that not all inquiry is created equal, however, these results may not be quite as paradoxical as first imagined. Teachers in the three-year RCT of inquiry practices in Los Angeles (Grigg, et al., 2013) noted that student-centred pedagogy was "difficult to implement" (p. 41), and teachers in the study were observed not to implement all aspects of inquiry successfully. Teachers emphasised 'gathering evidence' and 'questioning' but their students did not adequately 'communicate' or 'justify their explanations' (Grigg, et al., 2013). If other studies supporting enhanced student content learning facilitated by inquiry approaches in science are considered (e.g., Minner, et al., 2010) we observe that 'thinking' and 'drawing conclusions' from data were found to be key components associated with improving student achievement. Emphasis on ‘thinking’ and ‘drawing conclusions’ are also key in classroom interventions such as Cognitive Acceleration through Science Education (CASE) and Philosophy for Children (P4C), in which inquiry-orientated teaching and learning is the focus. Both programs have reported large positive effects on students’ levels of thinking, (Adey & Shayer, 1990; Oliver, Venville & Adey, 2012; Topping & Trickey, 2007) and gains in students’ self-esteem (Trickey & Topping, 2006). That some approaches to inquiry are demonstrably successful in improving students’ achievement in science resonates with CASE and P4C, in that students are expected to reflect, justify and explain ideas, use evidence, and reason. Similarly, as early as the 1960s, Schwab suggested that “scientific content and processes were intimately connected and inseparable” (1962, p. 28) and Minner et al. (2010) have noted, “the amount of active thinking, and emphasis on drawing conclusions from data, were in some instances significant predictors of the increased likelihood of student understanding of science content” (p. 493).

Faced with a myriad of methods, materials, and models of teaching and learning in science, it undoubtedly can be confusing for science teachers and science educators to discern research-supported practice. The “wave of enthusiasm for good quality evidence” (Goldacre, 2013, p. 18) suggests that teachers embedding research into their own practice need to be supported by advancing interest in and understanding of inquiry. While this study’s findings and those from other recent research challenge the orthodoxy of inquiry-oriented learning in science, one approach to addressing this challenge would be to garner evidence that identifies those aspects of inquiry that best promote science learning while positively engaging students. Rather than uncritically endorsing inquiry, science educators may best serve the needs of their students and those in schools by identifying and developing those features of inquiry-oriented teaching and learning that promote both positive engagement in science and the cognitive development needed for sound scientific literacy. As part of the wider science education community, science educators have the responsibility to ensure that the teachers we work with have access to preparation and professional development anchored in sound research evidence. One important aspect of this is to recognise that not all inquiry is created equal.

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