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Science Engagement and Literacy: A Retrospective Analysis for Indigenous and Non-Indigenous Students in Aotearoa New Zealand and Australia

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Abstract Previous research has underlined the importance of school students' engagement in science (including students' attitudes, interests and self beliefs). Engagement in science is important as a correlate of scientific literacy and attainment, and as an educational outcome in its own right. Students positively engaged with science are more likely to pursue science related careers, and to support science related policies and initiatives. This retrospective, secondary analysis of PISA 2006 national data for Aotearoa New Zealand and Australia examines and compares the factors associated with science literacy and with science engagement for indigenous and non-indigenous 15 year old students. Using a four step hierarchical regression model, our secondary analyses showed consistent patterns of influence on engagement in science for both indigenous and non-indigenous students in Aotearoa and Australia. Variations in students' interest, enjoyment, personal and general valuing, self-efficacy, and self concept in science were most strongly associated with the extent to which students engaged in science activities outside of school. In contrast, socioeconomic status, time spent on science lessons and study, and the character of science teaching experienced by students in their schools were the factors most explanatory of variations in science literacy. Yet, the factors that explained variation in science literacy had

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only quite weak associations with the suite of variables comprising engagement in science. We discuss the implications of these findings for science educators and researchers interested in enhancing students' engagement with science, and committed to contributing positively to closing the persistent gap in educational outcomes between indigenous and non-indigenous peoples.

Keywords Scientific literacy · Engagement in science · Out of school activities · Indigenous students · Secondary analysis · PISA

Multifaceted affective constructs such as *engagement in science*, and their component constructs, have a longstanding history in the science education research literature as important correlates for scientific literacy and attainment (e.g., Oliver and Simpson 1988; Osborne et al. 2003; Simpson and Oliver 1990; Saleh and Khine 2011). For example, in its description of scientific literacy, the Organisation for Economic Co-operation and Development (OECD) notes that literacy encompasses "…an individual's willingness to engage in science-related issues…" (2006, p. 23). More recently, however, engagement in science has been discussed as an outcome of science education important in its own right (e.g., Fensham 2007; Thomson and DeBortoli 2008). Thus, both engagement and literacy are important outcomes of science education as both contribute to students' choices around further study in science, and both can serve as barometers of the growth and development of national economies (OECD 2010). In practice and policy, these views have been manifested, for example, by the inclusion of affective constructs such as students' interest and self-concept in science, along with more traditional measures of science literacy and achievement, in comparative international assessments of science learning and performance. Specifically, the Programme for International Student Assessment (PISA) 2006 Australian report noted

> An important outcome of science education is the attitudes students have to science, how they respond to scientific issues, the motivation they have to excel in their science subjects(s), their interest in learning science at school and beyond school and their motivation to pursue a science related course or career (Thomson and DeBortoli 2008, p. 109)

As emphasised by Fensham, the fact that affective items were included in the 2006 PISA is "a clear message that affect about science, as well as cognition of it, is intended to be an outcome of learning for all students"(2007, p. 7).

Our central purpose in this paper is to better understand the factors associated with differences among indigenous and non-indigenous students' science engagement and literacy in science. To achieve this, we used retrospective, secondary analysis of the 2006 PISA national datasets for Aotearoa New Zealand and Australia. For our secondary analysis, we posed three interrelated questions, two primarily descriptive and one inferential. First, we sought a better comparative understanding of indigenous and non-indigenous 15-year-old Australian and Aotearoan students' literacy in science. Specifically, how do indigenous and non-indigenous high school students in Australia and New Zealand compare in terms of their science literacy performance, as measured by PISA 2006? Second, we sought to gain a stronger sense of the comparative patterning of indigenous and non-indigenous students' engagement in science. That is, how do indigenous and non-indigenous students in New Zealand and Australia compare in terms of their interest, enjoyment, valuing, self-efficacy and self-concept in science, as measured by PISA 2006?

Third, if substantive comparative differences were evident among these four groups' engagement and literacy in science, to what extent could observed differences be explained using data gathered through PISA 2006?

In particular, our approach included an examination of the 2006 PISA national datasets for Aotearoa and Australia to determine the extent to which 15-year-old students' engagement and literacy performance in science could be explained by factors commonly cited in the research literature, including: students' socioeconomic (SES) backgrounds (e.g., Ainley and Ainley 2010; McConney and Perry 2010); science-related activities outside of school (e.g., Basu and Barton 2007; Bulunuz and Jarrett 2010); time spent doing science in school (e.g., Stevenson et al. 1986; Stohr-Hunt 1996); and, the character of students' experiences in their science classrooms (e.g., Raved and Assaraf 2010; Stohr-Hunt 1996).

Based on the answers to these research questions, our focus in this paper is to consider the implications of our findings for science education practice and research, which purportedly aim to enhance engagement and literacy in science for *all students*. We underline that our purpose is *not* to compare Maori and Australian indigenous students. Rather, it is our intention to investigate whether persistent gaps between indigenous and non-indigenous students in the two countries continue to be evident for important outcomes in science education. We recognise that we are not alone in "closing the gap" efforts and acknowledge that they have been a concern of national governments and indigenous peoples throughout the world. We also believe, however, that a more complete understanding of longstanding gaps in achievement or engagement in science can be an important first step toward addressing potential social and educational inequities generally, and for informing science education practitioners and researchers regarding future practice and research, particularly. In summary, given this focus, our overarching aim in this secondary analysis is to contribute substantively, within the domain of science education, to addressing the "negative disparity in outcomes" (McKinley and Stewart 2009, p. 60) for indigenous peoples.

Context

Why focus on students' science engagement and literacy in science? Why compare the engagement and literacy in science of indigenous and non-indigenous students across Australia and Aotearoa New Zealand? Dillon (2009) and others have voiced the concern, we suspect shared by many in science education, that school science tends to benefit students who plan to pursue careers in science, but does not support and perhaps even alienates the majority of students who do not. Our interest in students' *engagement in science* stems, in the first instance, from this concern, in that better understanding and thereby improving engagement in science would seem to offer a potentially productive avenue to achieving the elusive goal of science literacy for all.

As noted above, engagement in science is most commonly portrayed as a multidimensional construct comprised of several sub constructs including students' attitudes, interests, enjoyment and self beliefs, that taken together suggest an openness and eagerness to understand and use science. In addition, science engagement is also likely to be associated with particular background contexts or factors (e.g., interest in subject, quality of teaching, resources, time of day, perceptions of relevance). Some of these contextual factors have been investigated, and reflect empirical associations with engagement. For example, the personal relevance and meaning of a science topic has been shown to be related to students' enjoyment and interest in engaging with the topic as well as their intention to further engage with science content (Ainley and Ainley 2010). These results suggest that an important aspect of student engagement is the mix between enjoyment and interest, something that Dewey (1933) called 'serious play'. Like other complex constructs, however, there is as yet no globally accepted characterization of what *engagement in science* or *science engagement* means.

Additionally, although *engagement in science* may hold different meanings for different stakeholders in different contexts, there is reasonable agreement that a *lack* of engagement in science can be problematic (Kuenzi et al. 2006; Oon and Subramaniam 2010; Raved and Assaraf 2010). For example, internationally, the proportion of students studying science, technology, engineering and mathematics has continued to decline (OECD 2006) leading to recommendations for changes in science and technology studies so that they are more attractive to students (Ainley and Ainley 2010). One explanation for the decrease in students studying science is that many, most specifically girls and indigenous students, find school science irrelevant, or not engaging, because of the perceived focus on 'facts' rather than including values and processes (McKinley and Stewart 2009; Tytler and Osborne 2010). A 'one size fits all' science curriculum is unlikely to be equally stimulating, engaging and meaningful for all students, as 'what interest girls … is unlikely to interest boys' (Tytler and Osborne 2010 p. 13).

Secondly, beyond our interest in better understanding science engagement, and our general commitment as science educators to science literacy for all, our own research (McConney, Oliver, Woods-McConney and Schibeci 2011) has focused specifically on ameliorating long-standing and considerable gaps in science literacy evident between indigenous and non-indigenous students. To date we have focused on the Australian case; however, to improve our understanding of patterns of difference between indigenous and non-indigenous students in science, in this study we have expanded our retrospective analysis to include Aotearoa New Zealand, and to examine engagement in science for both countries.

Typically, students in Aotearoa and Australia have been among the top performers in comparative international assessments like PISA, with many students scoring at the highest level in science literacy for PISA 2006. For example, 18% of 15-year-olds in New Zealand are in the top group in science, and Australia has been one of a handful of top performing countries over three rounds of PISA (OECD 2009). Although the two countries as a whole perform consistently well, however, we also know that they both continue to experience substantial differences in educational achievement and attainment, and in other life outcomes (health, life expectancy, employment, etc.) between indigenous and non-indigenous peoples, which with rare exceptions, favour the latter groups. PISA provides datasets of sufficient scale and quality to examine and perhaps better understand differences between indigenous and non-indigenous groups both within and across national boundaries.

Our third source of motivation for this study is a commitment to better understand science education from the *perspectives of students* by examining students' views and experiences of science in and out of schools. Students' poor or negative attitudes towards science, declines in students' enrolment in school science, declining interest in science and decreased intention to pursue science careers (Ainley and Ainley 2010; Aschbacher et al. 2010; Raved and Assaraf 2010) all highlight the need to better understand what is happening in school science *from the students' point of view*. Recent research shows that students identify variety and creativity in teaching as critical components of an interesting science classroom experience (Raved and Assaraf 2010) and report positive relationships between out-of-school activities and student engagement in science (Braund and Reiss 2006; Tran 2010). Furthermore, and in terms of support for pursuing science, students reported that few adults "at home or school enthusiastically invite students to learn about science or engineering, to value scientific ways of knowing, or to pursue an SEM degree or career" (Aschbacher et al. 2010, p. 580).

Thus, our aim is to add to our current collective understanding by examining data which provide insights into the context of the science classroom as well as what students are doing outside of class from Australian and Aotearoan indigenous and non-indigenous students' points of view. Both Australia and Aotearoa New Zealand are at critical points of change with the potential to better meet the needs of students in science. In Australia, for example, we are currently engaged with the development and implementation of a national curriculum that includes the human dimension of science as a major curriculum emphasis (ACARA 2011). Similarly, New Zealand introduced its latest version of the school science curriculum in 2008, with further work in 2010 targeting full implementation of a curriculum that emphasises the nature of science (Campbell and Otrel-Cass 2010). We believe that a better understanding of students' views can help inform science educators both in and out of the school setting, at these important junctures for both countries.

Thus, our interest in this line of inquiry continues to be fuelled by three overlapping features of our regional context that we believe have global application in science education. The convergence of these features in both the Australian and Aotearoan education settings has led to a need to understand—given the limitations of the data available—indigenous students' science engagement and literacy in contrast to that of their non-indigenous peers, as well as the factors strongly associated with science engagement, so that conversations around potential changes in educational practice and research can perhaps be better informed. Centred on the notion of reciprocal learning among nations, we believe that those 'down under' can learn from their OECD partners (and others), and importantly, that other countries can also learn from our shared experiences.

Method

This research is based on secondary analysis of the PISA 2006 datasets for Australia and Aotearoa New Zealand. PISA is an international standardized assessment of the performance of 15-year-old students in reading, mathematics, and science developed by the OECD. PISA has been administered on a cyclical three-year schedule beginning in 2000 with a focus on reading, followed in 2003 with a focus on mathematics and in 2006 with a focus on science. The overarching intent of the assessments is to support the further development of member countries' educational systems toward students' attainment of the skills and knowledge necessary for personal and working life in developed (industrialized) countries in a 21st century globalised economy (OECD 2004, 2007). Thus, the PISA surveys have made an important departure from other international assessments by decoupling the instruments from specific school curricula; rather, the assessment instruments are based on more holistic definitions of discipline-specific literacies.

For this retrospective, secondary analysis, the 2006 Australia and Aotearoa New Zealand datasets were collected from the PISA data housed at the Australian Council for Educational Research (ACER). To be able to identify and select those students who self-nominated as Maori (indigenous New Zealanders)—as these data were not provided in the archived dataset—we requested and received from the Comparative Education Research Unit[1] in the Aotearoa Ministry of Education an additional "ethnic background" variable, which we merged with the data gathered from ACER. In PISA 2006, the data for Aotearoa

[1] We express sincere appreciation to Maree Telford, Senior Research Analyst in the Comparative Education Research Unit and her colleagues at the Research Division, New Zealand Ministry of Education for their kind assistance in providing the student ethnic background data for New Zealand, PISA 2006.

New Zealand included 170 schools and 4,823 students representative of the population of 15-year-old students across the country. About 17% of this sample (827 students) identified themselves as Maori. Australia's sample included 356 schools and 14,216 students, of whom 1,080 (about 8%) self-identified as indigenous Australians. In PISA, each country's sample is drawn to be representative of the number of students enrolled in different types of schools (e.g., private or public, college preparatory or vocational schools, etc.) and locations (e.g., urban or rural). However, PISA typically employs a two-stage sampling frame by which schools are first sampled and then students are sampled within participating schools. This procedure means that sampling weights are associated with each student in the dataset because students and schools in a particular country may not have the same probability of selection, and some within-country strata are over-sampled to allow national reporting priorities to be met (OECD 2009). Such sampling design has the potential to increase the standard errors of population estimates. Thus, in this study, all descriptive and inferential statistics generated through secondary analysis of the PISA 2006 datasets for Aotearoa and Australia have taken account of the final student weights included in the dataset.

Descriptive analyses of science literacy performance were made using comparisons across four student groups organized by country and indigenous status. To achieve the comparisons in science literacy, we constructed student-wise averages using the set of five "plausible values" for science literacy provided in the dataset. So-called "plausible values" are multiple estimates of performance generated for each student. As explained by Wu (2005), in large-scale assessment programs such as the National Assessment of Educational progress (NAEP), Trends in International Mathematics and Science Study (TIMSS) and PISA, plausible values can be used to: (1) address concerns with bias in the estimation of population parameters when point estimates of latent achievement are used to estimate those parameters; (2) allow secondary data analysts to employ standard techniques and tools (e.g., SPSS, SAS procedures) to analyse literacy performance data that contain measurement error; and (3) facilitate the computation of standard errors of estimates when the sampling design is complex.

In addition to comparing science literacy for indigenous and non-indigenous 15-year-olds across the two countries, we also examined variables linked to students' engagement in science (interest, enjoyment, value, self-efficacy and self-concept) because of the importance of engagement as a global outcome of science education, as well as its potential as a correlate of science attainment (science literacy performance, in this case). As noted by Thomson and DeBortoli (2008) students' attitudes toward science in PISA 2006 included how they responded to scientific issues, the motivation they reported to excel in their science subjects(s), their interest in learning science at school and beyond school and their motivation to pursue a science related course or career. Thus, PISA 2006 seems to have been planned and implemented to avoid some of the pitfalls noted in previous reviews of the literature on measuring students' affect in science (Fensham 2007; Gardner 1975; Nieswandt 2008; Osborne et al. 2003). Indeed, as Thomson and DeBortoli (2008) point out, the latest PISA efforts to measure interest in science "gathered rich data on students' attitudes towards science not only by using the Student Questionnaire but also, for the first time, by embedding contextualised questions about student attitudes towards science in the actual test units" (p. 24). We therefore chose to make use of both PISA's measure of contextualised interest in science as well as students' general interest in science assessed using the Student Questionnaire.

Beyond students' contextualized interest in science and general interest in learning science, the PISA variables linked to students' *engagement* in science included measures of students' (1) enjoyment of science; (2) personal value of science; (3) general value of science; (4) self-efficacy in science; and, (5) science self-concept. [2]

PISA's index of *enjoyment of science* was 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*. A four-point scale with the response categories "strongly agree", "agree", "disagree" and "strongly disagree" was used. All items were inverted for scaling and positive values on this index indicated higher levels of enjoyment of science (OECD 2007). PISA's index of *personal value of science* was derived from 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*. Positive values on this index indicated positive student perceptions of the personal value of science. Similarly, PISA's measure of *general value of science* reflected students' level of agreement with statements like: *advances in science and technology usually improve people's living conditions*; and, *science is valuable to society.* Again, positive values indicated positive student perceptions of the general value of science (OECD 2007).

The index of *self-efficacy in science* reflected students' beliefs in their ability to perform various science-embedded tasks on their own. These included students' assessment of their ability in recognising the science question that underlies a newspaper report on a health issue; describing the role of antibiotics in the treatment of disease; and, predicting how changes to an environment will affect the survival of certain species. 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* was used, and positive values indicated higher levels of self-efficacy in science. Similarly, PISA's measure of *self-concept in science* was 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*. As with the other indices that make up *science engagement* in this study, positive values on this index for PISA 2006 indicate a positive self-concept in science (OECD 2007).

Findings

In answer to the first question posed for this study, and as shown in Tables 1 and 2 (descriptive statistics), the science literacy performance—as measured by PISA 2006—of indigenous Australian 15-year-olds lags that of their non-indigenous peers by 88 points (0.93 standard deviation [SD] units). For New Zealanders, the science literacy gap between indigenous and non-indigenous 15-year-olds is somewhat smaller at 62 points (0.61 SD). Figure 1 portrays these differences in standard deviation units. (We chose to use standard deviation units because they allow estimation and comparison of observed differences on a common scale. This is a widely accepted method for comparing the magnitude of observed differences among groups, particularly across multiple scales which may have different characteristics.) By any metric, the differences observed in science literacy between indigenous and non-indigenous students in both Aotearoa New Zealand and Australia are

[2] The make-up of this suite of affective variables to reflect student engagement in science was strongly influenced by Barry McGaw's invited Banksia lecture at Murdoch University earlier in 2010. Prof. McGaw is Chair of the Australian Curriculum, Assessment and Reporting Authority, Executive Director for the Australian Council for Educational Research and former Director for Education in the Organisation for Economic Co-operation and Development.

Table 1 Science literacy and engagement in science descriptive statistics for Australasian Students Participating in PISA 2006, by Country and Indigenous Status

Country/indigenous status		Science literacy	Science interest	General interest in science	Enjoyment of science	Personal value of science	General value of science	Science self-efficacy	Science self-concept
New Zealand non-indigenous	Mean	542.6	460.9	−0.0835	0.0344	0.0832	−0.0808	0.0414	−0.0338
	N	3938	3938	3933	3933	3928	3928	3931	3616
	Std. Deviation	101.66	95.41	1.01	0.98	1.03	0.98	1.04	0.95
	Std. Error of Mean	1.6298	1.5297	0.0163	0.0158	0.0165	0.0158	0.0166	0.0158
New Zealand Maori (indigenous)	Mean	480.1	462.2	−0.1697	−0.1946	−0.1542	−0.3825	−0.3108	−0.1815
	N	823	823	818	820	817	816	818	712
	Std. Deviation	97.74	100.94	1.07	0.95	1.01	0.97	1.03	0.93
	Std. Error of Mean	3.3233	3.4320	0.0364	0.0325	0.0346	0.0331	0.0353	0.0342
Australia non-indigenous	Mean	529.5	465.2	−0.2126	−0.0698	0.0222	−0.0440	0.1292	−0.0264
	N	13090	13090	13006	13019	12996	12997	13010	10939
	Std. Deviation	95.36	93.01	1.09	1.03	1.08	1.02	1.09	1.00
	Std. Error of Mean	0.8131	0.7930	0.0093	0.0088	0.0092	0.0087	0.0093	0.0093
Australia indigenous	Mean	441.1	474.6	−0.4345	−0.2911	−0.2191	−0.4132	−0.3484	−0.2642
	N	1080	1080	1046	1062	1046	1048	1054	799
	Std. Deviation	104.90	100.54	1.19	0.94	1.02	1.02	1.19	0.90
	Std. Error of Mean	5.1457	4.9315	0.0587	0.0465	0.0503	0.0503	0.0587	0.0521

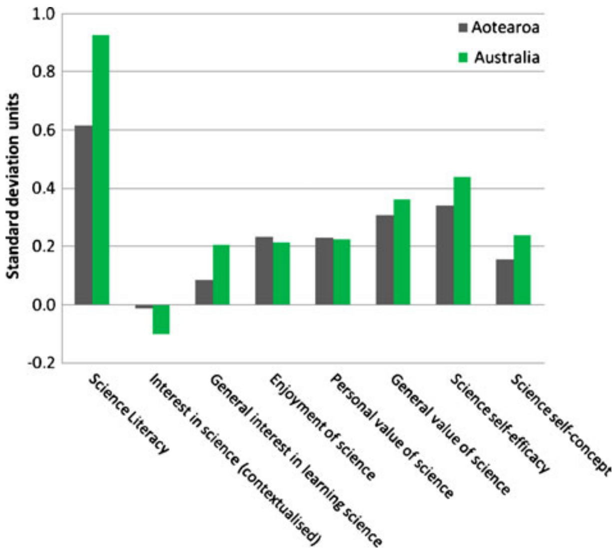
Table 2 Mean differences between indigenous and non-indigenous students in science literacy and engagement in science for Australia and New Zealand in PISA 2006

	Science literacy	Engagement in science variables						
		Science interest	General interest in learning science	Enjoyment of science	Personal value of science	General value of science	Science self-efficacy	Science self-concept
	Aotearoa New Zealand							
Mean difference between non-indigenous and indigenous students	62.4[a]	−1.3	0.1[a]	0.2[a]	0.2[a]	0.3[a]	0.4[a]	0.1[a]
Difference expressed in SD units	0.61	−0.01	0.08	0.23	0.23	0.31	0.34	0.16
	Australia							
Mean difference between non-indigenous and indigenous students	88.4[a]	−9.4[a]	0.2[a]	0.2[a]	0.2[a]	0.4[a]	0.5[a]	0.2[a]
Difference expressed in SD units	0.93	−0.10	0.20	0.21	0.22	0.36	0.44	0.24

[a] statistically significant at α=0.05

substantial and educationally meaningful. By one widely accepted yardstick, for example (Cohen 1988; Kirk 1996), the Aotearoa science literacy gap favouring non-indigenous students can be characterised as between medium and large, and the Australian difference as large.

Fig. 1 Mean differences between indigenous and non-indigenous students in science literacy and engagement in science expressed in standard deviation units



Tables 1 and 2, as well as Fig. 1, also provide answers for the second question asked in this study. For all measures included under the conceptual umbrella of student engagement in science (i.e., interest, enjoyment, valuing, self-efficacy, and self-concept) indigenous 15-year-olds in Australia and Aotearoa New Zealand lag their non-indigenous peers, to varying degrees. The only exception to this pattern is for contextualised interest in science, in which the questions were embedded in specific areas of science content, (e.g., acid rain, or tobacco smoking). In this case (as shown in Table 2 and Fig. 1) indigenous Australians led their non-indigenous peers by a modest 9 points (0.10 SD), and indigenous and non-indigenous New Zealanders reported relatively equal levels of contextualised interest in science. For the other six variables that comprise engagement in science, however, small to medium gaps favouring non-indigenous students were observed for both Australian and Aotearoan 15-year-olds. As detailed in Table 2, these observed differences—for general interest in science, enjoyment in science, personal and general valuing of science, science self-efficacy and self-concept in science—ranged in size between 0.08 SD and 0.44 SD; the majority of these differences can be characterised as small (although not necessarily trivial) using Cohen's (1988) yardstick. Additionally, in a majority of cases for this suite of engagement variables, the mean differences observed between indigenous and non-indigenous students in both Aotearoa and Australia are statistically significant.

In endeavouring to further understand the factors that explain the variability observed in engagement in science and science literacy performance for these four groups of Australasian students (the third question posed for this study), we subjected the data set to hierarchical multiple regression analysis (Cohen and Cohen 1983). For these analyses, we consistently used a four-step model, in which we controlled the entry order of explanatory variables. As portrayed in Table 3, for each science engagement or literacy outcome (dependent variable) our model included the following explanatory variables: 1) students' socioeconomic status (Index of Economic, Social and Cultural Status (ESCS) in PISA); 2) students' science activities outside of school; 3) students' time spent on science lessons or study; and 4) students' perceptions of science teaching—the characteristics of classroom science students experienced in their schools. For each of the 4 groups of students (Australian and New Zealander indigenous and non-indigenous students), and for each dependent variable of interest (science literacy and seven engagement in science variables), Table 3 provides the proportion of variance uniquely contributed by each of these explanatory variables (or sets of variables).

For New Zealand, the factors most strongly associated with variations in science literacy are students' SES (11 to 15% of variance observed in literacy) and time spent on science (13 to 19%), for both indigenous and non-indigenous students. For science literacy in Australia, SES plays the strongest role (9 to 11%), with time spent in science lessons or science study a relatively close second (7 to 8%). Again, this was the case for both indigenous and non-indigenous Australian students. However, while the proportions of variance in science literacy explained by students' socioeconomic circumstances are similar for Australia and New Zealand (ranging between 9 and 15%), the variance in literacy explained by time is not. Time spent in science lessons or study accounted for 7 to 8% of the observed variability in science literacy for Australia, but substantially more for New Zealand students, and particularly for students who self-identified as Maori (19%).

Again using the 4-step hierarchical regression model described above, for the seven science engagement variables included in this study, the patterns of explained variance portrayed in Table 3 are remarkably consistent. (To assist in displaying these patterns, dark grey shading is

Table 3 Proportions of variance explained for science literacy and engagement (interest, enjoyment, valuing, self-efficacy and self-concept) by SES, science activities outside of school, time and science teaching experienced for Australian and new Zealand indigenous and non-indigenous 15-year-old students

Dependent variable:	**Proportion of variance explained by:**															
	Socio Economic Status				***Science Activities*** (things students do outside of school related to Science e.g., Watch TV about science; books; websites; magazine articles; clubs)				***Time*** (How much time do you typically spend per week on: a. regular lessons; b. outside of class lessons; c.study/homework)				***Science Teaching*** (student investigations + hands on activities + focus on applications/models + interactions)			
	AUS		**NZL**		**AUS**		**NZL**		**AUS**		**NZL**		**AUS**		**NZL**	
	I[a]	**N**[b]	**I**	**N**	**I**	**N**	**I**	**N**	**I**	**N**	**I**	**N**	**I**	**N**	**I**	**N**
Science Literacy	.089 (9%)	.107 (11%)	.107 (11%)	.152 (15%)	.005 (1%)	.057 (6%)	.018 (2%)	.032 (3%)	.079 (8%)	.068 (7%)	.191 (19%)	.129 (13%)	.066 (7%)	.035 (4%)	.034 (3%)	.035 (4%)
Science Interest	.025 (3%)	.005 (1%)	.005 (1%)	.003 (0%)	.171 (17%)	.219 (22%)	.206 (21%)	.246 (25%)	.011 (1%)	.006 (1%)	.012 (1%)	.023 (2%)	.050 (5%)	.014 (1%)	.018 (2%)	.030 (3%)
General Interest	.069 (7%)	.021 (2%)	.023 (2%)	.014 (1%)	.166 (17%)	.276 (28%)	.195 (20%)	.251 (25%)	.022 (2%)	.016 (2%)	.036 (4%)	.045 (5%)	.074 (7%)	.020 (2%)	.026 (3%)	.024 (2%)
Enjoyment	.048 (5%)	.033 (4%)	.034 (3%)	.036 (4%)	.216 (22%)	.335 (34%)	.294 (29%)	.326 (33%)	.020 (2%)	.026 (3%)	.050 (5%)	.047 (5%)	.029 (3%)	.024 (2%)	.020 (2%)	.029 (3%)
Personal Value	.043 (4%)	.029 (3%)	.028 (3%)	.036 (4%)	.185 (19%)	.280 (28%)	.255 (26%)	.250 (25%)	.011 (1%)	.019 (2%)	.042 (4%)	.035 (4%)	.046 (5%)	.037 (4%)	.025 (3%)	.036 (4%)
General Value	.049 (5%)	.042 (4%)	.032 (3%)	.048 (5%)	.122 (12%)	.142 (14%)	.112 (11%)	.131 (13%)	.020 (2%)	.013 (1%)	.045 (5%)	.012 (1%)	.030 (3%)	.041 (4%)	.026 (3%)	.036 (4%)
Science Self-efficacy	.077 (8%)	.068 (7%)	.034 (3%)	.076 (8%)	.065 (7%)	.133 (13%)	.124 (12%)	.141 (14%)	.016 (2%)	.016 (2%)	.051 (5%)	.033 (3%)	.027 (3%)	.018 (2%)	.016 (2%)	.012 (1%)
Science Self-concept	.044 (4%)	.035 (4%)	.022 (2%)	.033 (3%)	.176 (18%)	.198 (20%)	.187 (19%)	.197 (20%)	.014 (1%)	.021 (2%)	.027 (3%)	.033 (3%)	.054 (5%)	.028 (3%)	.046 (5%)	.035 (4%)

a = Indigenous Students; b = Non-Indigenous Students used in Table 3 to signify proportions of explained variance that are 10% or greater; similarly, lighter grey shading is used to signify proportions of variance that are between 5 and 10%; and no shading signifies proportions of explained variance less than 5%.)

Quite starkly different from the findings for science literacy, the factor most closely associated with variations in all seven engagement variables is science activities (i.e., science-related activities students do outside of school)—which contributed between 11 and 34% of explained variance across the groups organised by country and indigenous status. For each of the seven engagement in science variables, the proportions of variance explained by the other 3 factors in the regression model (SES, time spent in formal science lessons or study, and the characteristics of science teaching encountered in the classroom) pale in comparison. As depicted in Table 3, this is seen to be particularly so for time spent on science lessons and study, and somewhat surprisingly for science teaching (the characteristics of classroom science experienced by these students). This patterning of the factors that contribute (relatively) most strongly to the explanation of variability in the seven engagement variables holds true for both Aotearoa New Zealand and Australia, and across indigenous and non-indigenous students, as shown in Table 3.

As noted above, it appears quite surprising that the nature of students' experience in science classes seems to have little association with the seven variables comprising engagement in science. How can this be explained? One potential avenue is to look at students' self-reports of the characteristics of science taught in their classes (see Figs. 2 and 3). Two things are apparent (among others) from these two figures: (1) the frequency distributions show that in both Australia and Aotearoa New Zealand, indigenous and non-indigenous students experience science teaching that is qualitatively quite similar in terms of the teaching and learning activities engaged in science classes; (2) the three teaching strategies that may most strongly reflect student autonomy or agency in doing science are those that are experienced least often by indigenous and non-indigenous students in both countries.

Specifically, students were asked in the PISA questionnaire: *When learning < school science > topics at school, how often do the following activities occur?* As shown in Figs. 2 and 3, the three teaching/learning strategies least experienced by indigenous and non-indigenous students in both Aotearoa and Australia, are:

- Students are allowed to design their own experiments (Q34 h)
- Students are given the chance to choose their own investigations (Q34 k)
- Students are asked to do an investigation to test out their own ideas (Q34 p)

These three strategies, when juxtaposed against the others listed, would seem to offer the greatest opportunity for student control (agency) in their own science learning, within the school context.

Discussion

In this retrospective analysis our findings show that in Australia and New Zealand, indigenous students continue to trail their non-indigenous peers in science literacy and engagement, as measured by PISA. For science literacy in Aotearoa and Australia, the observed differences are substantial and educationally meaningful. Similarly, for engagement in science, indigenous students in Australia and New Zealand lag their non-indigenous peers, albeit by more modest margins than seen for science literacy, on all

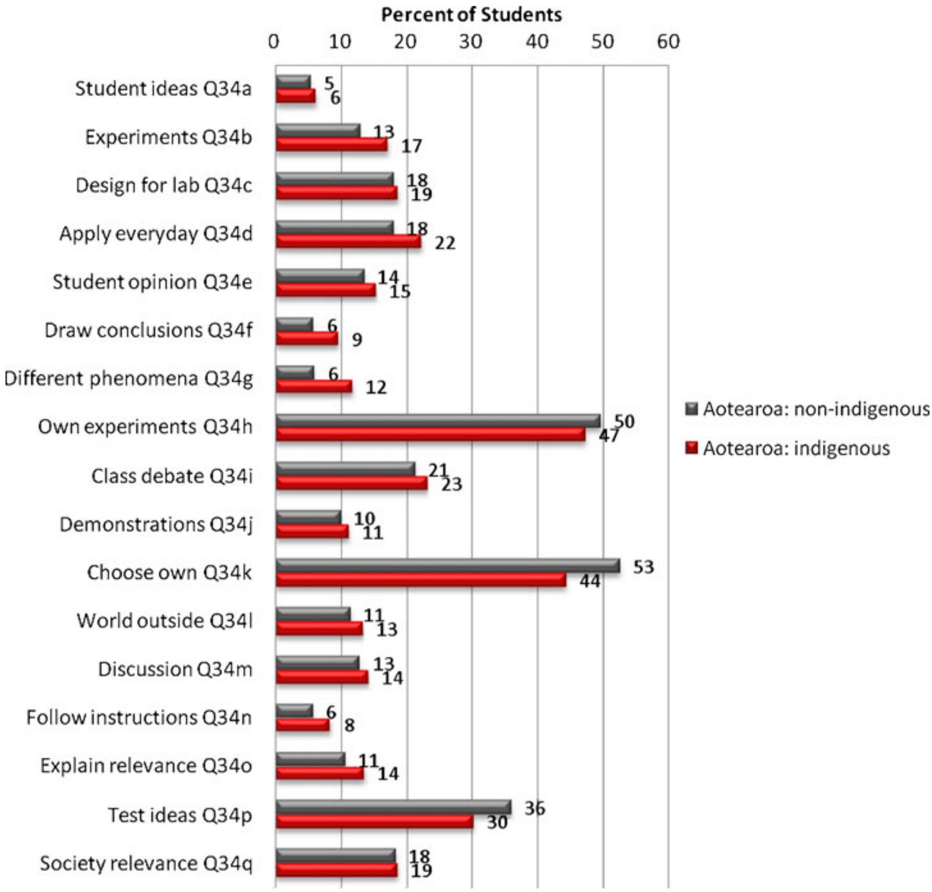


Fig. 2 Percent of Aotearoa New Zealand 15-year-old, indigenous and non-indigenous students who report 'never or hardly ever' experiencing various learning/teaching strategies in school science

engagement measures included in this secondary analysis. The one exception to this is contextualised interest in science, for which the questionnaire items are embedded in specific topics of science content (e.g., acid rain, or tobacco smoking), and for which indigenous Australian students led their non-indigenous peers, and no difference was observed between indigenous and non-indigenous students in New Zealand. In our view, the persistence of these gaps warranted further analysis to determine the extent to which observed differences could be explained by factors previously argued to be important including SES, out-of-school science-related activities, time spent doing science in school and students' characterisations of their experiences in science classrooms.

Importantly, for science literacy and the seven engagement variables examined, our analyses show that the patterning of explained variance is consistent across indigenous and non-indigenous student groups, in both New Zealand and Australia. Interestingly, however, the explanation of variability in science literacy is different to that for science engagement. For all four groups, organised by country and by indigenous status, the factors most strongly associated with science literacy are SES and the time students typically spend each week on science. In contrast, the factor most strongly associated with the seven engagement

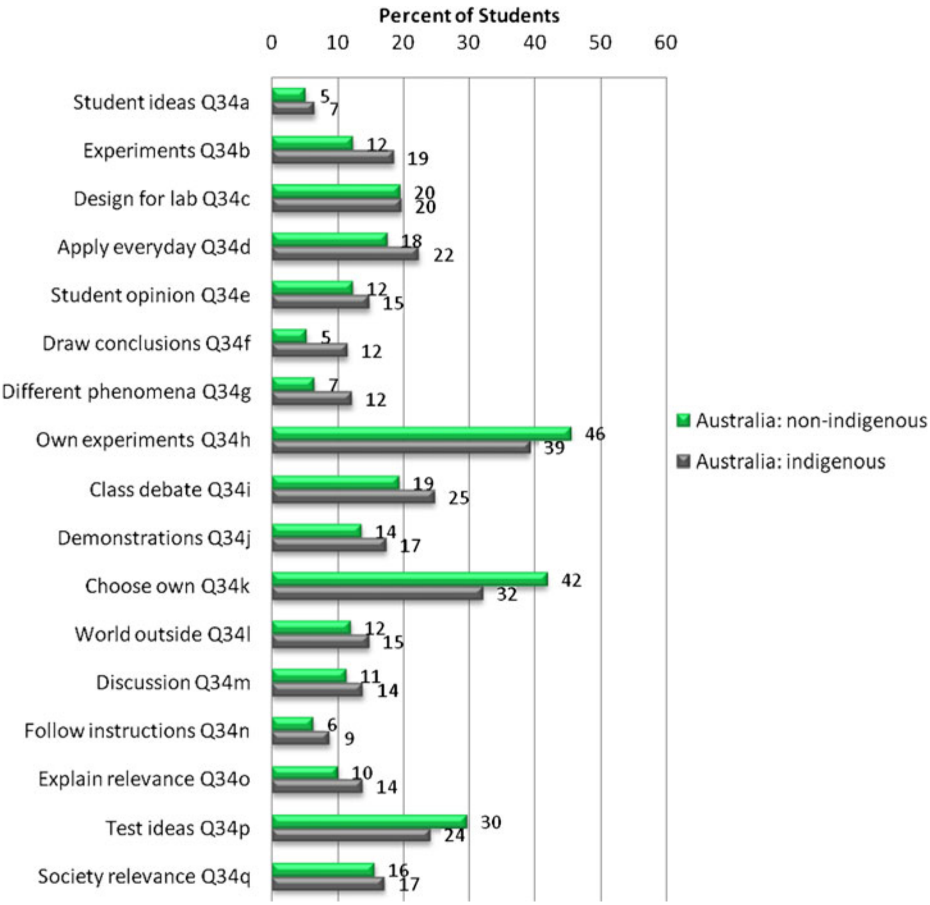


Fig. 3 Percent of Australian 15-year-old, indigenous and non-indigenous students who report 'never or hardly ever' experiencing various learning/teaching strategies in school science

variables is science-related activities students do outside of school. Further, for the seven variables comprising science engagement, the proportions of variance associated with the other 3 factors in our model (i.e., SES; time spent in science lessons or study; characteristics of classroom science) are notably small by comparison; this is especially so for time spent on science and students' characterisations of classroom science. In summary, substantial gaps continue to exist, in both science literacy and engagement, between indigenous and non-indigenous students in both Aotearoa and Australia; equally consistently across the four groups, science-related activities outside of school is the factor most strongly associated with 15-year-old students' engagement in science.

Gaps in Science Literacy and Engagement

In attempting to meaningfully contribute to closing long standing gaps between indigenous and non-indigenous students through better understanding science literacy and engagement in science, our findings point in a number of interesting directions. First, although New Zealand's and Australia's 15-year-olds have performed well overall in science for all rounds of PISA, our findings show a continuing and substantial gap in science literacy between indigenous and non-indigenous students for both countries. These findings are consistent with those from previous studies (see, for example, McConney et al. 2011) and again raise concern that, despite government-led efforts to reduce literacy gaps through special programs, there continues to be little improvement or change. Furthermore, the idea of a robust curriculum or attempts to standardise the science curriculum have not yet paid off in terms of improving indigenous students' science literacy. The gap between indigenous and non-indigenous Aotearoan 15-year olds is especially noteworthy since a Māori language version of the science curriculum is taught at both primary and secondary levels and has been in place since the mid-1990s (Aikenhead & Elliott, 2010; McKinley 1996).

In our view, our findings can thus be interpreted in a number of ways. One would be to suggest that the Māori version of the science curriculum is not helping Māori students improve their science literacy (close the gap with their non-indigenous peers). This may be because in the 1990s there seemed to be more of an emphasis on developing a national science curriculum in Māori rather than addressing potential barriers for teachers trained and immersed in a Western science culture but trying to teach in a different culture (McKinley 2007). Additionally, the persistence of the indigenous lag in science literacy may be the result of students struggling to recognise the connections between science as taught in the schools and their own cultural heritage and activities (McKinley 2007).

On the other hand, another way to interpret the results is that there may indeed be improvements in science literacy for Māori students, but that these are not reflected in large-scale standardized assessments, such as PISA, even though the PISA instruments have been decoupled from specific curriculum. A renewed focus on the nature of science for the 2008 New Zealand curriculum may yet, however, help to address the science literacy gap for Māori students, and further emphasises the need for additional research that examines science literacy across cultural groups in New Zealand, Australia and elsewhere.

Second, for engagement in science, indigenous and non-indigenous students in Aotearoa reported similar levels of contextualised (topic-embedded) interest while Australian indigenous students reported higher levels of contextualised interest than their non-indigenous peers. For this retrospective analysis this was the only engagement construct for which indigenous students were either similar or ahead of their non-indigenous peers. There are two ways that higher embedded interest can be interpreted (Ainley and Ainley 2010). Students may *recognise that they do not know much about the subject and feel that they need to learn more* since the questions are embedded in particular topical science content questions. Or, alternatively, notwithstanding their knowledge about a topic, students may be genuinely interested in learning more about a specified topic. Either way, the topical issues are *not* presented in a typical school science manner (e.g., biology, chemistry, physics or geology) but instead are framed within an authentic topic. In our view, these findings are noteworthy for both science education practice and policy, in that they underline the importance of authentic, relevant settings and topics for indigenous students in both Australia and New Zealand.

In reporting the impact of a work-integrated learning program on the attitudes of undergraduate, indigenous New Zealanders' attitudes towards science, Coll and Paku (2011), found improvements in students' attitudes toward science and science careers. These students were mentored in their work experience by graduate students and although these were undergraduate, rather than school students, the results support our contention that authentic science experiences are an important contributor to positive science engagement. We can speculate that the involvement in what students perceived as authentic tasks was a contributor to attitude improvement. Clearly, a lack of engagement in science can be exaggerated for indigenous students, especially when the home culture is quite different to the school science culture (Aikenhead & Elliott, 2010, p. 324). Making science content more relevant and authentic may therefore be especially important for indigenous students. Aikenhead and Elliott further emphasise this fundamental issue of basic understandings being viewed from completely different (sometimes polar) worldviews (2010). For example, an anthropocentric view of sustainability would have very different implications when contrasted against a view of "sustainability as a responsibility to Mother Earth" (2010, p. 324).

In another study examining students' engagement with science, Tytler and Osborne (2010) identified gender as one of three explanatory factors. Differences in the topics that may engage male students (explosive chemicals, black holes and outer space, how atom bombs function and biological and chemical weapons) as compared to those that may engage female students (what dreams mean, cancer, first aid, exercise and fitness and STDs) emerged, suggesting that the content of the curriculum may not appeal to all students. Again, these findings support our contention that curriculum needs to be overtly relevant to students. If gender is one area where clear differences in interests lie, then perhaps asking girls what interests them might be educative for us as science teachers. In a similar way, asking indigenous students what interests them may also guide science educators in our understanding of relevant, authentic science content for students located within indigenous cultures.

What, therefore, do these findings say to closing gaps in science literacy and engagement in science? Chronic under-representation of indigenous students in secondary and tertiary sciences leads to inequalities for indigenous people that includes lower employment in resource- or technology-related careers, low numbers proportionally of engineers and scientists, and less participation as scientifically literate citizens in the "social fabric of their country" (Aikenhead & Elliott, 2010, p. 324). These inequalities highlight the need to better understand what works for closing the science education gap. Our findings emphasise the importance of authenticity or relevancy of science content for indigenous students. The incorporation of indigenous ways of knowing in Australian and Aotearoan national curricula would seem to be a promising first step in addressing the needs of students and contributing to the elusive goal of science literacy for all.

Science Engagement: Building Understanding from Students' Perspectives

The 2006 round of PISA, with its in-depth focus on science, provided a unique opportunity to investigate science literacy and engagement from the student perspective by examining their characterisations of science in and out of school. One of the most interesting results of this secondary analysis is that student characterisations of science experiences *in school* do not add much to the explanation of variability in science engagement. We showed this to consistently be the case for both indigenous and non-indigenous students in Aotearoa and Australia. In other words, the differences between those students who were highly engaged and those least engaged were not associated with differences in activities within science classrooms. This finding is consistent with those in other studies that have shown that despite the recent call for an emphasis on experimentation and the quality of labs to improve interest (Oon and Subramaniam 2010; Raved and Assaraf 2010), experimentation does not always generate positive interest in science (Holsterman et al. 2010).

At first glance the implications of these student perspectives may not seem helpful because it may seem as though typical science classroom activities are not associated with, or explanatory of, students' science engagement. However, when the data are considered from a different viewpoint, with an emphasis on activities *least* reported by students, interesting patterns emerge that may provide some insight. In PISA 2006 for New Zealand and Australia, students reported seemingly appropriate science classroom activities such as those that emphasise everyday contexts, are hands-on and practical lab-based, or activities that require students to explain their own ideas. In contrast, however, activities in which students are able to design their own experiments, are provided opportunities to choose their own investigations or allowed to do investigations to test out their own ideas were those reported as *least frequently experienced*. That is, the science classroom activities in which students have a high degree of student autonomy were those consistently reported as being the least frequently experienced by both indigenous and non-indigenous students in Australia and New Zealand. In one sense, the consistency of these results across all four groups of students is reassuring in that there is little apparent difference in how different student cohorts experience classroom science. At the same time, however, there also seems to be a consistent pattern that shows that, from the students' perspective, the science classroom experience can be characterised as lacking true autonomy and/or control for students in science.

Other studies may also inform our thinking about the importance of student autonomy (or lack of autonomy) in science engagement. For example, Bulunuz and Jarrett (2010) reported that high school students categorised as 'high interest' in science had more input (autonomy) in their middle school class experiences when compared to 'low interest' students (p. 76). Similarly, when interviewed, practicing scientists reported that school experiences in which teachers allowed and encouraged them as students to carry out independent investigations contributed to their continued interest in science (Jones et al. 2010). Engaging content was not enough, nor was the use of hands-on activities. Instead, the opportunity to explore science independently was an important factor in these practicing scientists' continued engagement with science.

Students' views and experiences of science *out of school* provide further insight and understanding of their engagement in science. This retrospective analysis confirms, for example, the important role of out-of-school activities, consistent with the views of interviewed students who reported a clear need for positive out-of-school science-related activities (Raved and Assaraf 2010), and the need for experiences such as visits to science museums, nature centers, zoos, as well as home related activities such as care of animals, and watching science programs on TV (Bulunuz and Jarrett 2010). These out-of-school activities ('free-choice' activities) appear to be more important than formal school science in distinguishing between low and high interest students. This is further confirmed by a comprehensive study of more than 1,000 science museum visitors (Falk and Needham 2011). In this long term study, visitors to a science museum consider the science centre strongly influential in their knowledge and attitudes about science and technology, and this was especially so for minority and low-income individuals. The importance of these 'informal' or 'free-choice' science activities in sparking student interest and engagement in science has been underlined by Bell et al. (2009), and is also consistent with other recent findings (Stocklmayer et al. 2010; Falk and Dierking 2010; Holsterman et al. 2010; Jones et al. 2010; Tran 2010).

Clearly, the role of out-of-school activities in relation to the development of students' interest and engagement in science is something we cannot ignore (Jones et al. 2010); consistently, what students do outside of school has been shown as strongly related to their interest and engagement in science, and in this study is much more explanatory of engagement than the nature of activities within science classrooms. These somewhat surprising results seem to support the value of out of school experiences for students both out of and in the classroom. We readily acknowledge, however, that given the inherent nature of the data examined that it is also possible that students interested in science are those most likely to engage in out of school science activities, rather than the other way around as we have suggested. This potential notwithstanding, as is the case with many affective constructs in education, it is perhaps most likely that there exist bi-directional, recursive relationships between out-of-school activities and the various science engagement variables examined here. In that case, teachers' attention to out of school activities would likely pay considerable dividends toward improving students' engagement in science. Of course, careful thinking and planning are required on how to increase the potential for learning science through leveraging activities outside the classroom (Braund and Reiss 2006). For example, Basu and Barton (2007) have suggested the incorporation of "students' lived experiences within a particular family and community" (p. 468) into learning environments to capture the social relationship between schools and homes.

How then, can we build science engagement for students? Our findings emphasise the importance of authenticity and relevance of science content as well as more autonomous settings and activities for students. Perhaps out-of-school science-related experiences are attractive and influential because they can be characterised as allowing high degrees of student control or autonomy and also high relevancy or authenticity. With awareness of this, science teachers could incorporate activities that allow for increased student control as well as ensure that science content is relevant to students' lives, interests and concerns. Further, teachers, if aware of the importance of out-of-school activities, could provide out-of-school links to in-school activities by using science magazines and television video clips, providing opportunities for museum trips and other out-of-school experiences. These links may be even more important for students who may not have these types of opportunities at home. Additionally, the value of these two notions of student control (autonomy, agency) and relevancy (authenticity) of science content can be seen together as providing an important message for science educators beyond the classroom by informing the development of state and national curriculum, underlining the need to support out-of-school activities and providing direction for further science education research.

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