MINISTRY OF EDUCATION
TE TĀHUHU O TE MĀTAURANGA

Teaching in New Zealand: findings from international studies

Inquiry-based or teacher-directed science? Evidence from PISA

Summary

This paper explores a highly polarised debate in the literature on teaching methods: the effectiveness of inquiry-based science instruction and teacher-directed science instruction in raising students' scientific competences and wider dispositions towards science. The paper also provides insight into how the use of these teaching practices in New Zealand compares in an international context. These findings will be of interest to teaching professionals as well as providers of teacher education.

Key Findings

- New Zealand students experience high rates of *teacher-directed science instruction*. Teacher-directed science instruction appears effective at raising students' scientific literacy.

- The effectiveness of inquiry-based science instruction appears highly variable. Moderate use is unrelated to lower student performance, although not as effective as teacher-led methods.

- At high levels of use, inquiry-based science instruction shows a problematic relationship to achievement and the precautionary principle suggests this level of use should be discouraged.

- Inquiry-based methods show value in helping students develop positive attitudes to science.

- There is a generalisable 'sweet spot' combining both methods, with teacher-directed methods in most to all classes and inquiry-based in some, with the inquiry-based instruction supplementary – e.g., as an end-of-module extension – to a general strategy of teacher-directed instruction.

- To be effective, inquiry-based instruction relies on good school discipline, pre-teaching of key content, as well as adequate teacher guidance, teacher planning time and school materials.

Background

As the Prime Minister's former Chief Science Advisor explained, "science education is not just for those who see their careers involving science but is an essential component of core knowledge that every member of our society requires" (Gluckman, 2011). Scientific literacy underscores myriad everyday decisions about our health and our use of technology and our treatment of natural resources. It gives us tools to understand and predict the world around us and to recognise and reject false theories.

Written for policy makers with influence in science teaching as well as providers of Initial Teacher Education and Professional Learning and Development, the key findings will also be of interest directly to science teachers.

Results

Science Instruction Methods

> The main message that emerges … is that the quality of the material and human resources of a science department, and the kinds of science activities offered to students have a weaker impact on student performance than how much time students devote to learning science and how teachers teach science (OECD, 2016b, emphasis added).

In 2015, as part of the three-yearly research study PISA (the Programme for International Student Assessment), 15-year-old students around the world were asked questions designed to gauge how often they experienced 'inquiry-based' and 'teacher-directed' instruction methods in their science lessons.

Teacher-directed science instruction involves the teacher providing explanations, demonstrations and extensions of content, and leading discussions to direct what students learn.

Inquiry-based science instruction involves the teacher having less control of the lesson, often only minimally guiding the lesson, while students explore processes of science for themselves.

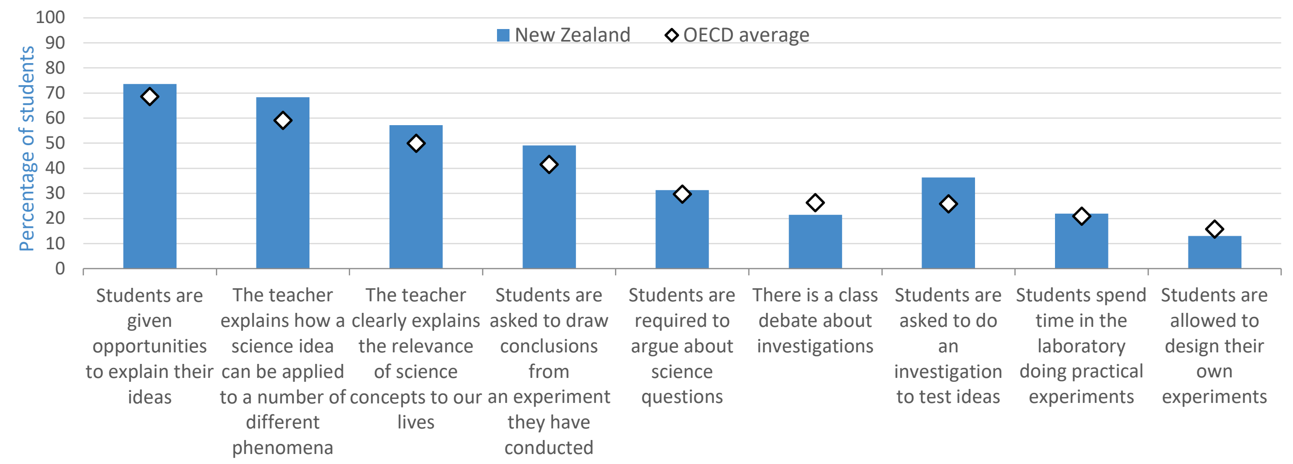
There is an active debate in pedagogical circles about which of these two methods is 'better' (eg, Bennett, 2018), a debate which has been ongoing, in one form or another, for a great many years (eg, Stone, 1996).

Frequency of exposure to these methods

New Zealand 15-year-olds experience comparatively high rates of inquiry-based science instruction, according to the PISA index of inquiry-based instruction. Some inquiry-based activities are more common than others; however, patterns of use are similar to the international average (Figure 1). The one exception is that New Zealand students are more likely to report that they are asked to do investigations to test ideas (36%) than are their counterparts across the OECD[1] (26%).

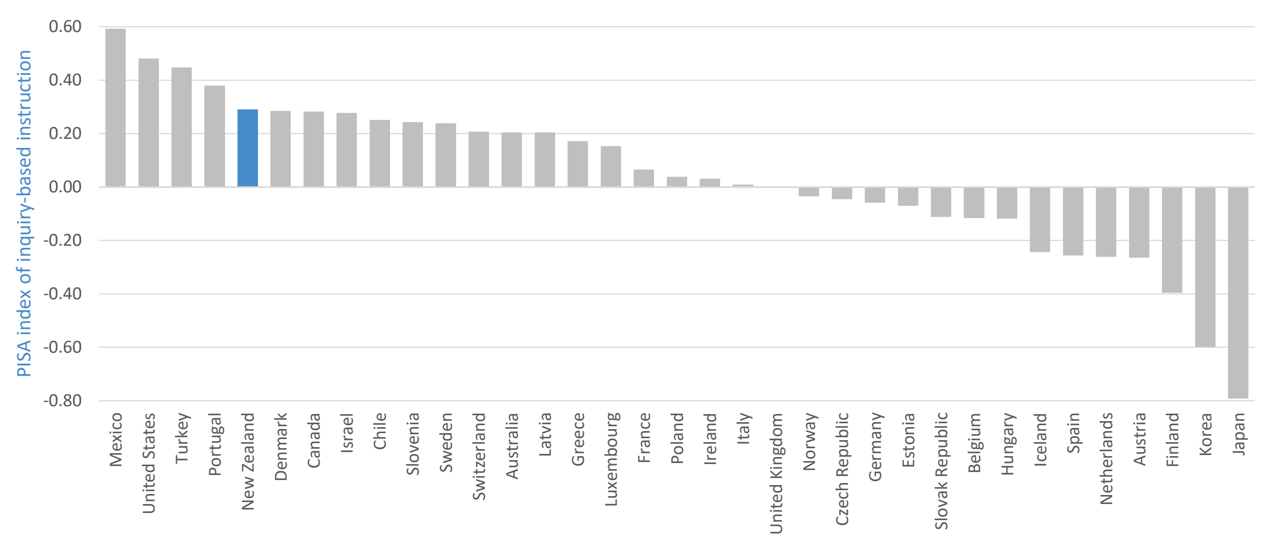
Interestingly, students in Year 10 (i.e., pre-NCEA 'core science') also report slightly higher exposure to inquiry-based science activities, on average, than students in Year 11.

Figure 1. Percentage of students reporting that these inquiry-based instruction methods happen in 'most' or 'all' science lessons



The use of inquiry-based methods is especially high compared to most countries in the quarter of our schools with the most disadvantaged students (Figure 2). In many countries, inquiry-based methods are more frequently used with the more advantaged students, who tend to be higher performers on average than disadvantaged students, irrespective of instructional style, due the head start afforded by their background.

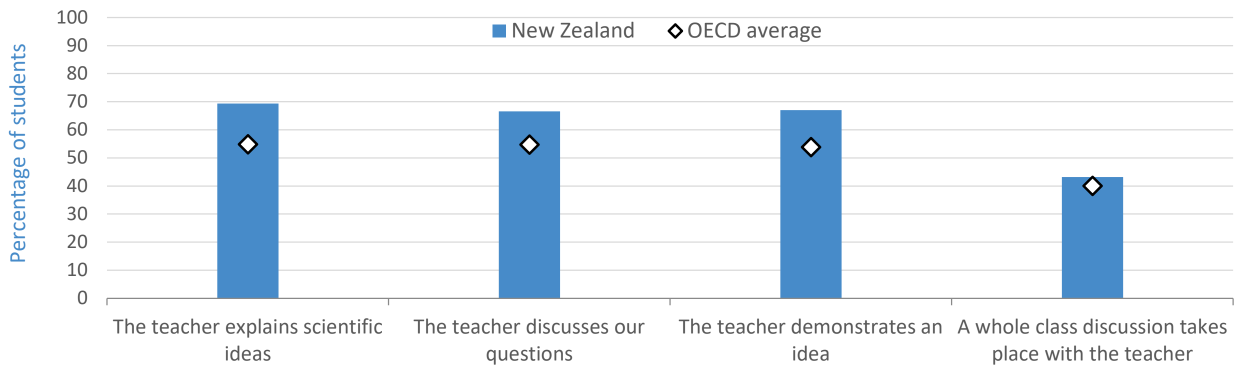
Figure 2. Comparison of disadvantaged students' exposure to inquiry-based instruction methods



[1] The Organisation for Economic Cooperation and Development.

Students in New Zealand experience high rates of teacher-directed instruction, as defined by PISA, in their science classes and higher than the OECD average. Rates of use of these methods in New Zealand are similar to rates of use in Australia and the United States. New Zealand students are exposed to similar rates of teacher-led, whole-class discussions in science compared to the OECD average, but higher rates of the other teacher-led behaviours (Figure 3).

Figure 3. Percentage of students reporting that these teacher-led instruction methods happen in 'many' or 'every or almost every' science lesson



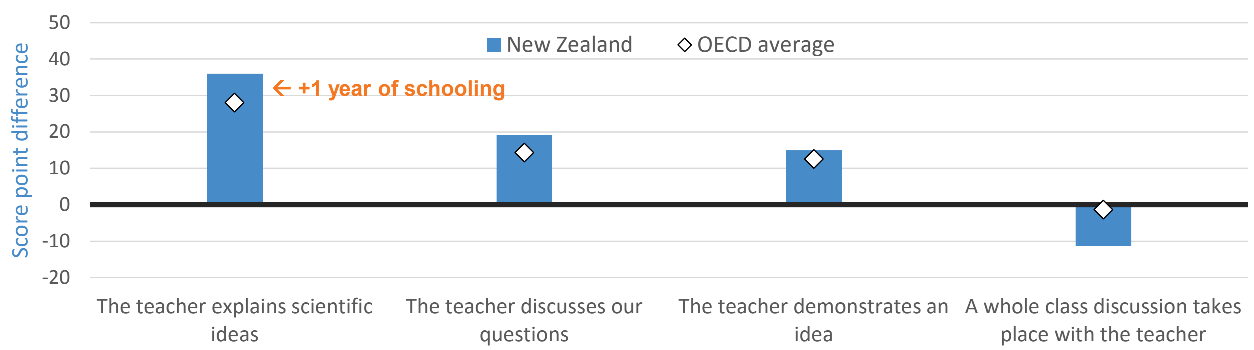
This relatively high rate far teacher-directed methods may be partly a result of the inclusion of questions about teachers interacting with and responding to students (ie, leading 'whole-class discussions' and 'discussing student questions'). These practices are uncommon in some countries because of very large class sizes or cultural expectations that students should not disrupt the class with their questions. Classes in such countries may revolve around the teacher substantially more (essentially 'teacher-delivered' instruction) than classes rated high for 'teacher-directed' instruction in PISA. It is therefore useful to understand 'teacher-directed' here to mean teacher-centred with responsiveness to questions from the class.

How these methods are linked to students' scientific literacy

Based on the PISA index of teacher-directed instruction, frequent exposure to teacher-directed methods (ie, in most or all science lessons) is linked, on average, to higher scientific literacy. In New Zealand, the increase is seven PISA score points, equivalent to about one school term[2], after accounting for student and school factors[3].

Not all teacher-directed methods that students were asked about are associated with performance in the same way (Figure 4). The more teacher-centred methods are linked to higher scientific literacy, whereas the frequent use of whole-class discussions are linked, on average, to lower scientific literacy.

Figure 4. Difference in PISA score points associated with these teacher-led instruction methods in 'many' or 'every or almost every' science lesson



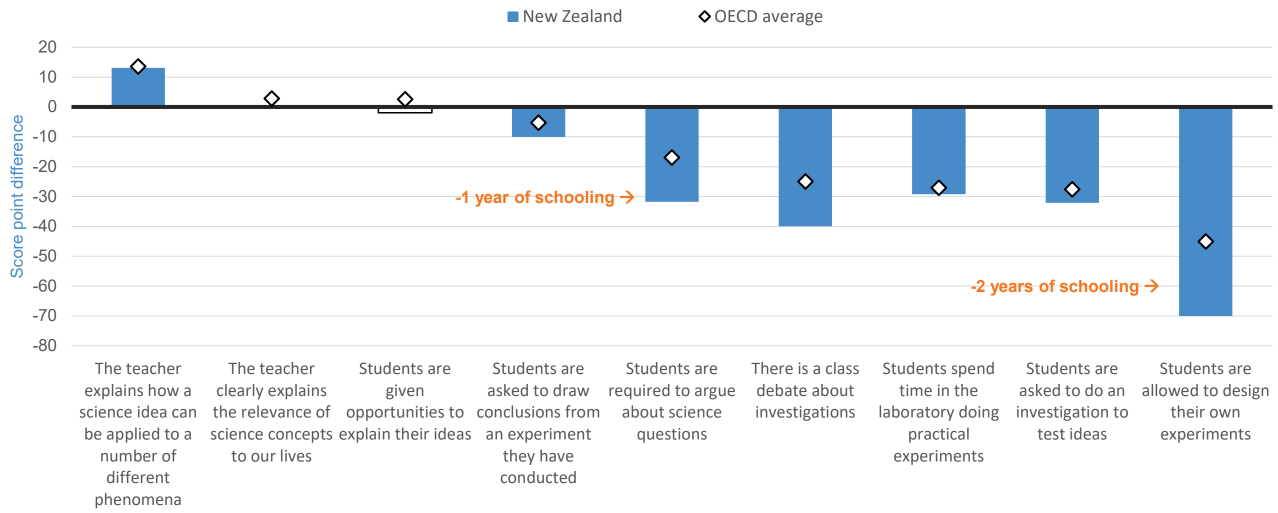
[2] Thirty PISA score points are roughly equivalent to one school year. For more detail, see OECD (2016a), box I.2.1.

[3] Such as the socioeconomic background of the student and the average socioeconomic background of the school.

Based on the PISA index of inquiry-based instruction, frequent exposure to inquiry-based science instruction is linked, on average, to lower scientific literacy, after accounting for student and school factors. In New Zealand, it is associated with a decrease in science performance of 14 points, equivalent to about half a year of schooling – the second highest negative association with performance among the PISA 2015 countries.

Some inquiry-based activities are associated with lower science performance equivalent to a year or two of schooling (Figure 5).

Figure 5. Difference in PISA score points associated with these inquiry-based instruction methods in 'most' or 'all' science lessons.



Note: For New Zealand, all statistically significant changes from the national mean of PISA score points are shown in blue. For the OECD average, all points represent statistically significant changes from the mean.

Not all inquiry activities students were asked about are associated with performance in the same way. The frequent use of the less teacher-guided inquiry methods, such as students designing their own experiments, is related to much lower scientific literacy, whereas teachers frequently explaining the applications of scientific ideas is linked, on average, to higher scientific literacy.

Moreover, although we would expect high exposure to inquiry-based methods to be linked to higher performance in at least the PISA 'procedural knowledge' subscale, this is not the case. The relationship between high use of inquiry-based science instruction and lower scientific literacy holds across all PISA subscales of science competency, scientific knowledge types and content areas. This negative relationship also holds true for all groups in New Zealand: advantaged/disadvantaged students, advantaged and disadvantaged schools, ethnic groupings and genders.

Other studies have reached similar conclusions. In 1970-71, the first multi-country education research project, the First International Science Study (eg, Comber & Keeves, 1973) found that, across the 19 participating countries including New Zealand, 'inquiry learning' was not linked to higher achievement. Moreover, international data also attests to a high level of positivity towards inquiry-based instruction methods in New Zealand (Box 1).

Box 1: Teachers' views

93% of Year 7-10 teachers in New Zealand agree or strongly agree that 'My role as a teacher is to facilitate students' own inquiry'.

94% agree that 'Students should be allowed to think of solutions to practical problems themselves before the teacher shows them how they are solved'.

82% agree that 'Thinking and reasoning processes are more important than specific curriculum content'.

79% of Year 7-10 teachers in New Zealand agree or strongly agree that 'Students learn best by finding solutions to problems on their own'.

Source: Teaching and Learning International Survey (TALIS) 2013/14

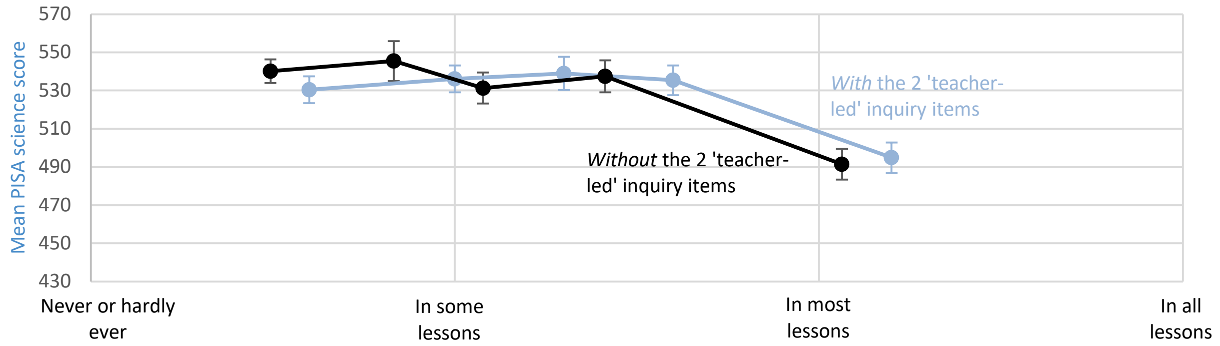
Are all of these items 'inquiry'?

It is debatable whether all activities asked about are 'inquiry' methods. A factor analysis[4] suggests there are three items ('The teacher explains…', 'The teacher clearly explains…' and 'Students are given opportunities to explain…') that, in the context of New Zealand teachers, align better with the 'teacher-directed' items. Interestingly, these are the only three items not related to lower science performance (see Figure 5). However, even after removing two non-contentiously 'teacher-led' items ('The teacher explains…' and 'The teacher clearly explains…'), there is virtually no change in the relationship to lower achievement. That is, there is effectively no issue with these items being included in the index of inquiry-based science instruction.

A non-linear relationship with achievement

Further analysis shows that the relationship between inquiry-based instruction and scientific literacy is not a straight line, not a dose-response relationship. It is only at high frequency rates of exposure to inquiry-based instruction – the top quintile, equivalent to the use of inquiry-based methods in most (or more) science lessons – that inquiry-based instruction is statistically related to lower science literacy. This is true whether or not we include the two 'teacher-led' items in the inquiry scale – the drop at the top end is similar (Figure 6).

Figure 6. Quintiles of mean exposure to inquiry-based science instruction (averaged across all inquiry-based activities), with the related mean score for PISA scientific literacy



The teacher-directed and inquiry-based 'sweet spot'

Analysis of this data by international consulting firm McKinsey (Chen, Dorn, Krawitz, Lim & Mourshed, 2017) revealed a 'sweet spot' combining teacher-directed instruction in most to all science classes and inquiry-based instruction in some to many classes. This was linked to the highest score-point differences from group means across all geographic groupings (North America, Europe, Oceania, 'high-performing Asia').

The below analysis suggests this mix is generalisable across New Zealand contexts: one or both of the 'sweet spot' (middle-right quadrant) and 'danger zone' (bottom-left quadrant) are evident across socioeconomic and cultural groups (examples in Figure 7). Statistically significant differences from the mean (at the .05 level) are shown in bold. This analysis compares score-point differences to the group, rather than the national, average.

Fifteen percent of low-decile students experience low use of inquiry methods and low use of the 'teacher-directed' practices (top-left quadrant), suggesting stricter 'traditional' instructional methods than the PISA indicator of 'teacher-directed instruction' is measuring. For low-decile students, these practices are also associated with higher than group-average science competences, though not as high as the 'sweet spot'. Eight percent of disadvantaged students and 12 percent of advantaged students experience this sweet spot.

[4] A statistical method of determining how well individual items hold together to describe elements of the same factor.

Figure 7. Difference in PISA score points associated with different balances of instruction methods

Low decile (compared to average performance of students in low decile schools)

Inquiry-based science instruction	Teacher-directed science instruction: None to a few	Some to many	Most to all
None to a few	**31**	25	28
Some to many	19	19	**66**
Most to all	-5	7	25

← The 'sweet spot'

Disadvantaged students (compared to average performance of disadvantaged students)

Inquiry-based science instruction	Teacher-directed science instruction: None to a few	Some to many	Most to all
None to a few	20	25	45
Some to many	11	**26**	**56**
Most to all	-27	-7	11

Advantaged students (compared to average performance of advantaged students)

Inquiry-based science instruction	Teacher-directed science instruction: None to a few	Some to many	Most to all
None to a few	-14	2	-7
Some to many	-25	-1	14
Most to all	**-67**	**-37**	0

Māori students (compared to average performance of students who identify as Māori)

Inquiry-based science instruction	Teacher-directed science instruction: None to a few	Some to many	Most to all
None to a few	**28**	**43**	6
Some to many	9	20	**56**
Most to all	**-34**	-7	15

Asian students (compared to average performance of students who identify as Asian)

Inquiry-based science instruction	Teacher-directed science instruction: None to a few	Some to many	Most to all
None to a few	19	**38**	25
Some to many	**-47**	30	**47**
Most to all	**-45**	-21	2

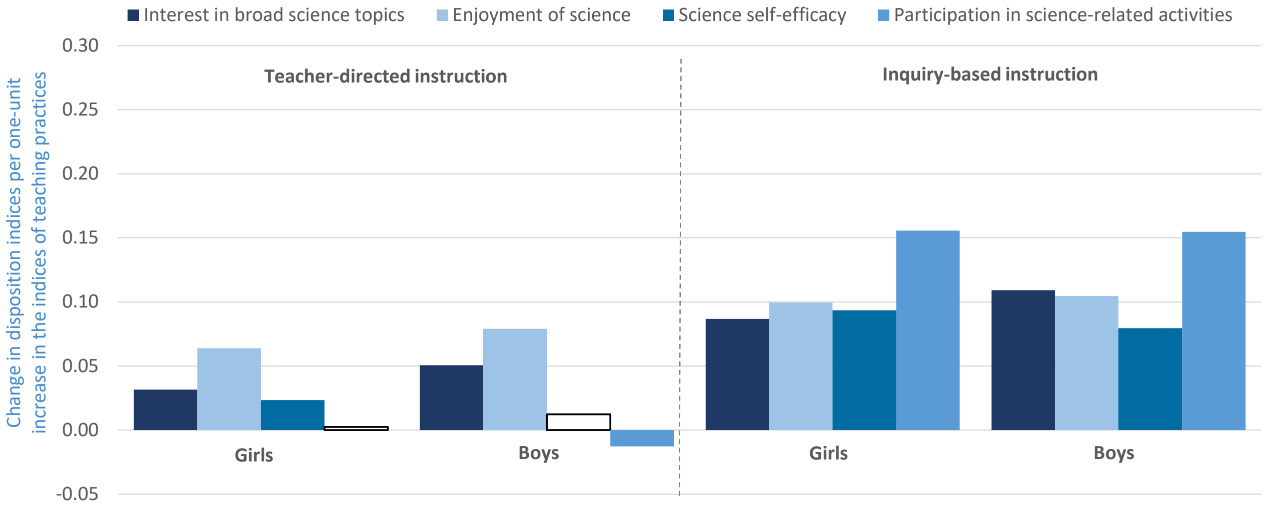
How these methods are linked to students' dispositions toward science

Controlling for the five different science instruction methods that students were asked about in PISA 2015[5] , the use of inquiry-based science instruction is weakly to moderately linked to more positive attitudes and dispositions towards science, on average, across the OECD (Figure 8). That is, inquiry-based methods are related to engagement and dispositions more than teacher-directed methods. This holds true even after accounting for students' socioeconomic status (SES), gender, year level, science performance and number of science subjects studied. The change in attitudes towards science related to inquiry-based instruction is slightly stronger for girls than boys.

Broadly, the same pattern is true of teacher-directed instruction methods, though the relationship is weak.

Attitudes examined were students' enjoyment of science, interest in broad science topics, science self-efficacy[6] and science epistemic beliefs[7] . Also, on average across the OECD, though not in New Zealand, the use of inquiry-based methods is linked to slightly higher odds of girls (but not boys) expecting a career in a science-related field.

Figure 8. Change in attitudes toward science associated with higher use of these instruction methods



Note: White bars denote statistically non-significant changes.

After controlling for student characteristics and school factors, New Zealand has the strongest relationship between higher use of inquiry-based science instruction and student-reported enjoyment of science, although the strength of this relationship is still modest. New Zealand also has one of the strongest relationships between higher use of inquiry-based methods and students' epistemic beliefs (Mostafa, Echazarra & Guillou, 2018). However, the strength of these relationships in New Zealand are not significantly different from those seen in the UK, Australia and Ireland.

After controlling for student characteristics and school factors, New Zealand has one of the strongest relationships between higher use of teacher-directed science instruction and student enjoyment of and interest in science. However, here too the strength of these relationships is modest.

The use of inquiry-based science instruction also appears to be linked to students feeling a stronger sense of agency in being able to influence environmental issues (see Jang-Jones & Webber, 2019).

[5] Teacher-directed instruction, inquiry-based instruction, adaptive instruction, teacher support and teacher feedback. (The questions asked are designed to allow analysis that can isolate the use and effects of each method.)

[6] That is, their self-belief in their ability to solve science problems or achieve science goals.

[7] That is, their appreciation for the cumulative nature of the scientific method and valuing of scientific approaches. (See Kirkham & May (2016) for more data on science self-efficacy and science epistemic beliefs.)

Discussion: Why is frequent inquiry-based instruction linked to lower science competences?

One possible explanation for this negative relationship between inquiry-based instruction and science literacy is that inquiry-based activities are difficult to do well. This is a demanding teaching strategy that requires specific resources and school climates for it to work well (Mostafa, Echazarra & Guillou, 2018).

The minimally guided inquiry methods are especially well suited to contexts where students have a high level of prior knowledge – and self-discipline – to provide 'internal' guidance (Kirschner, Sweller & Clark, 2006). Supporting this hypothesis, across all countries in PISA 2015, students in science classes with a 'poor disciplinary climate'[8] performed worse in science when exposed to inquiry-based activities. This suggests that using inquiry-based learning to try to 'engage' students in classes where noise, disorder and wasted time are the norm is unlikely to raise the science performance of these students.

It appears that inquiry-based science instruction is less effective in disadvantaged schools and works best for advantaged students in advantaged schools. Further OECD analysis of the PISA 2015 data shows that on average in Australia, and therefore likely similar in New Zealand, inquiry-based methods are linked to slightly higher scores among top performing students yet to lower scores among lower performing students (Mostafa, Echazarra & Guillou, 2018). Similarly, Hattie and Yates (2014) also caution that while lower-knowledge students often express a preference for low-guidance, inquiry-based lessons to lessons based on direct instruction, these students learn less from inquiry lessons than their higher-knowledge peers, thus increasing the knowledge gap.

The demanding nature of inquiry-based science instruction raises the question of whether teachers who use inquiry-based activities very regularly have adequate time to plan these activities well. A review of science in New Zealand primary schools by the Education Review Office came to similar conclusions about the difficulty of integrating science content well into inquiry-based methods:

> An inquiry-based approach to teaching and learning in primary schools has become increasingly common in recent years. … In the hands of a confident and capable teacher, inquiry learning provided opportunities for students to develop valuable thinking and questioning skills for scientific investigation. However, in some schools the approach risked losing the integrity of science in the process. … High quality examples of successfully integrating science into inquiry-based teaching and learning were limited. (Education Review Office, 2012)

Another possible explanation is that teachers may be overusing inquiry activities that provide too little guidance to students. A meta-analysis of inquiry-based methods by Lazonder and Harmsen (2016) suggests that inquiry-based science instruction is most effective when it is supported by adequate amounts of guidance from the teacher. Similarly, a broader meta-analysis by Kirschner, Sweller and Clark (2006) found that minimally guided methods, including inquiry-based learning methods, were consistently less effective than approaches that strongly emphasise teachers guiding the student learning process. A meta-analysis of experiments into inquiry-based science teaching (Furtak, Seidel, Iverson & Briggs, 2012) found that student-led activities had mean effect sizes of .50, whereas teacher-led activities had mean effect sizes of .90.

Furthermore, even well-used inquiry methods, when used frequently, may simply be slower at building students' knowledge and skills. That is, having students inquire into – and reach accurate and well-developed conclusions about – any element of scientific knowledge, process and procedure are, by definition, more time-consuming than more direct teaching and learning of the same.

[8] A poor disciplinary climate includes: there is noise and disorder, students don't listen to what the teacher says, the teacher has to wait a long time for students to settle down, and students cannot work well.

Conclusion

Based on the analyses here and the wider literature on inquiry-based science instruction, teacher-directed science instruction appears, on average, effective at raising students' scientific literacy. By contrast, the effectiveness of inquiry-based science instruction appears to be highly variable.

Many inquiry-based activities appear perfectly fine in moderation, although not as effective on their own as teacher-led instructional methods. However, rather than a straight-line 'dose-response' effect, there is a 'too much' effect. That is, at high levels of use, inquiry-based science instruction shows a problematic relationship to achievement and the precautionary principle would suggest this level of use should be discouraged.

A lot of factors need to be aligned for inquiry-based methods to be effective. Inquiry-based instruction is resource intensive in terms of teacher planning time and school materials, and relies on productive learning behaviours in class (ie, low on noise, disorder and wasted time), pre-teaching of key content to students, and the right amount of teacher guidance.

A high use of inquiry methods has the potential to decrease equity when used with students who don't have the necessary strong understanding of key content to bring to the activity, and more so where school behaviour systems aren't effectively developing positive learning behaviours. That is, frequent use of inquiry-based instruction methods appears unlikely to meet the needs of disadvantaged students. Similarly, the evidence doesn't support there being cultural 'preferences' between ethnic groupings in what works to raise achievement. Indeed, based on this data such a belief may have the potential to hold back disadvantaged groups.

In New Zealand, a relatively high proportion of disadvantaged students experience high exposure to inquiry methods. Conversely, in many countries inquiry-based methods are used more frequently with more advantaged, higher-performing students.

Inquiry-based methods have a place in schools, and show value in helping students develop positive science-related attitudes. A little high-quality inquiry, in some classes, goes a long way. However, using inquiry-based learning simply to try to 'engage' students in classes, although intuitively appealing, is unlikely to raise their science performance, especially in classes where noise, disorder and wasted time are the norm.

Relatedly, a generalisable 'sweet spot' exists that combines the use of both methods, with teacher-directed methods in most to all classes and the use of inquiry-based activities in some classes. There are a plethora of ways that teachers can and do create such blended approaches. Evidence from recent meta-analyses of research into the effectiveness of inquiry-related methods can provide insight into which types of blends hold the most promise for raising student learning, competences and dispositions. For instance, just-in-time teaching of content to quickly provide students enough domain knowledge for an inquiry, just before an inquiry, places a high load on students' working memory and is therefore unlikely to be an optimal instructional strategy.

Most promising are approaches that blend some inquiry into a primarily teacher-directed teaching and learning programme as a supplement at the end of the learning module, when students have a deeper proficiency with the domain knowledge. It is reasonable to use inquiry learning once sufficient domain knowledge has been developed, for instance to cap a culmination of prior learning and knowledge development with a related inquiry project, thus expanding on that strong foundation.

Research methods and data sources

To assess science performance, PISA 2015 used 184 science test items of varying difficulty. Students also filled out a detailed context questionnaire, which included questions on their experiences of teaching practices in their science classes, their enjoyment of and interest in science, and their expectations of a career in science.

This paper examines teaching practices mainly from the point of view of students' experiences of these practices. Although instruction methods used in the classroom are often nuanced and interlinked, the questions asked of students allow us to analyse specific aspects of instruction individually or in combination. Students don't require any understanding of pedagogical theory to accurately report on how often they experience specific activities and behaviours in their classes.

Teacher data included here is from the Teaching and Learning International Survey (TALIS 2013/14), a large-scale international research study of teachers and teaching, in particular teachers of students in Years 7 to 10.

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Disclaimer: Opinions, findings and conclusions expressed in this paper are those of the author.

Published August 2019 by:
Evidence, Data and Knowledge
Ministry of Education

ISBN (web): 978-1-77669-829-5

For further data and information on the international studies, please visit **https://www.educationcounts.govt.nz/topics/research**.

For further information, questions or discussion around additional analysis and potential topics please contact **Requests.EDK@education.govt.nz**

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