The transformative potential of engaging in science inquiry-based challenges

The ATSE Wonder of Science Challenge

By Louisa Tomas, Cliff Jackson and Karen Carlisle

In 2012, the Australian Academy of Technological Sciences and Engineering (ATSE) piloted the *Wonder of Science Challenge* with a view to enhance school students' interest in Science, Technology, Engineering and Mathematics (STEM). Students in 15 schools across northern Queensland were provided with an inquiry-based research problem and presented their findings at a regional competition. This paper explores the experiences of one primary school teacher and his students. Evidence drawn from the analysis of interview and survey data suggests that the key features of the Challenge—namely, open inquiry, engagement with practicing scientists, and the student presentations—had transformative outcomes for both teacher and students.

INTRODUCTION

Concerns that the supply of professionals with science, technology and engineering qualifications is insufficient to meet the current and future needs of Australia's growing industries are supported by the findings of a recent report that examined the status of science in Australia (Office of Chief Scientist, 2012). In particular, the broad trend of lower participation rates in secondary and tertiary STEM subjects is reported as a key vulnerability of the Australian science system (Office of the Chief Scientist, 2012. See also: Ainley, Kos & Nicholas, 2008; Lyons & Quinn, 2010; Organisation for Economic Cooperation and Development [OECD], 2012).

The decline in students' interest in school science, particularly as they progress into secondary school, is well documented within the literature (e.g. Hackling, Goodrum & Rennie, 2001; Osborne, Simon & Collins, 2003; Tytler, 2007). Studies into the reasons behind this decline have identified three key factors: the nature of the traditional science curriculum (i.e. suggestions that it is not meaningful or interesting to school students [Aikenhead, 2005; Fensham, 2006; Lyons, 2006]); a shortage of suitably qualified teachers that see science classes allocated to non-science trained teachers (Harris & Farrell, 2007; Tytler, 2007); and teachers' poor self-efficacy for teaching science. While it has been suggested that students' interest in science can be enhanced by adopting inquiry-based approaches that "link with their lives and interests and broader aspirations" (Tytler, Osborne, Williamson, Tytler & Cripps, 2008, p. viii), non-science trained teachers or those with poor self-efficacy for teaching science are more likely to use teacher-centred modes of instruction (Osborne et al., 2003).

THE ATSE WONDER OF SCIENCE CHALLENGE

The Wonder of Science Challenge (referred hereafter as 'the Challenge') was proposed by the ATSE as one way of addressing concerns about students' interest in science and the decline in STEM participation. The objective of the Challenge is to "increase enthusiasm for science- and engineering-based careers through an enhanced science and technology experience" (ATSE, Queensland Division, 2012, p. 2). In 2012, the ATSE piloted an annual competition for students in Years 6 to 9. In Term 3, students from 15 schools across northern Queensland participated in the pilot program. Students were required to research a given inquiry-based problem linked to *The Australian Curriculum: Science* (Australian Curriculum, Assessment and Reporting Authority [ACARA], n.d.). The ATSE provided a different problem for each year level. The Year 7 problem, for example, was to design a solar powered vehicle to complete a revolution of a circle in 10 seconds.

The Challenge commenced with a professional development day for teachers from participating schools in July 2012. The day provided teachers with an opportunity to learn about the Challenge and school-based research projects, and connect with Young Science Ambassadors (YSAs). The YSAs were post-graduate scientists selected by the ATSE to provide students and teachers with in-school support and mentoring during the Challenge. YSAs were allocated to each school and support facilitated through face-to-face visits and email communications.

Students undertook the research projects over a six-week period from August 2012. Schools were responsible for making pedagogical decisions about the implementation of the research projects. At the conclusion of their research, schools selected a team of four students to represent them at a one-day forum held in Townsville, North Queensland. The forum comprised of competitive rounds where pairs of teams took turns to present and defend the validity of their methodologies and findings. Judges with science expertise rated the teams' presentations and subsequent discussion. Students chose a presentation format that best displayed the results of their investigation or design.

This paper examines the experiences of one teacher, Mr Matthews (pseudonym), and his Year 7 class at Wattle Tree Primary School (pseudonym). Mr Matthews is an experienced primary school teacher who has been teaching for 10 years. At the time this study was conducted, it was his second year teaching Year 7 at Wattle Tree Primary. While Mr Matthews considers himself to be an effective classroom teacher, he is continually looking for ways to improve his teaching practice so as to cater effectively for the diverse students in his care. Given that a priority of the Challenge is to "inspire and develop the love of science in young people" (ATSE, Queensland Division, 2012, p. 2), we were interested in examining whether the format of the Challenge—and its approach to engaging students in science—was effective in capturing students' interest and initiating pedagogical change for their teacher.

RESEARCH DESIGN AND PROCEDURES

A mixed-methods design that generated qualitative and quantitative data was employed in this study. Data collection comprised of teacher and student surveys that included a variety of question and response formats such as dichotomous questions, multiple-choice questions, Likert-style rating scales and open-ended questions allowing for free response. The experiences of a case study class were investigated in greater detail via an in-depth semi-structured interview with the teacher and a student focus group. Triangulation of data and perspectives increased the credibility and trustworthiness of findings.

To gather macro-level data about participating students' experiences of the Challenge, students from all participating schools were invited to complete a survey after the culminating student forum (N=27, from seven schools). Items were drawn or adapted from a number of instruments for students' science attitudes (Barmby, Kind, & Jones, 2008; OECD, 2005). The survey also included items that were designed by the research team to explore students' experiences of the Challenge.

To gain a more fine-grained perspective of participants' experiences, a case study of Mr Matthews' class was conducted as an outcome of critical sampling methods (Patton, 2002). Data were gathered from Mr Matthews using two surveys. The first was employed before the Challenge and examined his views about science teaching. Items were drawn from a number of instruments published within the literature that examine teacher attitudes to science and science teaching (Enochs & Riggs, 1990; Murphy & Beggs, 2005; OECD, 2006). Mr Matthews completed a second survey after the student forum day. This survey, designed by the research team, examined his views about teaching science following his participation in the Challenge, and his overall experience.

An individual semi-structured interview was conducted with Mr Matthews after the student forum day. The interview explored his experience of all phases of the Challenge and questions were framed around the following themes: implementing the Challenge; student engagement and learning arising from the student research projects; working with YSAs; the student forum day; and reflection on the experience.

Four students from Mr Matthews' class who participated in the Challenge—Mark, Jane, John and Rebecca (pseudonyms) —were selected to participate in an end-of-project focus group interview. The purpose of the focus group was to provide deeper insight into how the Challenge was experienced by the students, as well as their attitudes towards science. The student focus group interview explored the following key themes: the student research projects; working with the YSAs; the student forum day; and interest, enjoyment and learning arising from the Challenge.

In order to analyse the survey data, a coding framework was developed to guide the coding of participants' responses. Codes were analysed for descriptive statistics such as frequencies and percentages. Responses to open-ended questions were first read to identify the range of responses before being aggregated into broader themes. Audio recordings of the teacher interview and student focus group were fully transcribed and processed with *NVivo Version 10* (QSR International, 2012) software to identify emerging themes related to participants' experience of the Challenge.

FINDINGS

Participants identified three key features of the Challenge as being transformational: the open inquiry afforded by the student research project; engaging with practicing scientists (the YSAs); and the student presentations. The following sections present the analyses of data that illuminate the ways in which these features of the Challenge were transformational for Mr Matthews and his students.

Open Inquiry Afforded by the Student Research Project: Transformations for Mr Matthews

Mr Matthews reported a number of outcomes that arose from engaging his students in a more open inquiry afforded by the student research project that were personally transformative: an improvement in his self-efficacy for teaching science; a positive change in his views on the importance of different approaches to teaching science; and an appreciation of the impact of a more open inquiry approach on his students' engagement and science knowledge.

The initial teacher survey asked Mr Matthews questions related to his confidence in developing students' science inquiry skills, and his views about the importance of different approaches to teaching science. In the end-of-project survey, Mr Matthews was asked to respond to these questions again. Analysis of these data found that Mr Matthews' confidence in developing all of the science inquiry skills surveyed (i.e. those included in the F-10 Australian Science Curriculum: *Questioning and predicting; Planning and conducting investigations; Processing and analysing data and information; Evaluating;* and *Communicating* [ACARA, n.d.]) improved after his participation in the Challenge.

Mr Matthews reported that he came to view adopting different approaches to teaching science (e.g. giving students opportunities to explain their ideas; students conducting investigations to test their own ideas and draw conclusions) as being more important than he did before the Challenge. At interview, he explained that he was surprised by the impact of a more open inquiry approach on his students' engagement and science knowledge:

> *"I was really surprised by how good it was to have an open-ended scientific investigation where the students really took it on board to develop their own scientific knowledge. Different terms—variables, independent variables, friction, diameter of circles—we did some work as a class about that, explaining what was needed, explaining the timeline; that was a fair bit of teacher-directed, whole-class learning. But from that point on, the students really developed their own depth of knowledge, their own scientific language…I felt every student achieved to their highest potential. There was a lot of higher-order thinking going on by the time they got to the class presentations."*

Mr Matthews further described the depth of science learning that this approach facilitated:

> *"There was science wrapped up in the investigation that I had never even considered and because the class got to listen to everybody's presentation and discuss the presentations, there was a lot more science covered through the investigations and critiquing the presentations than I could possibly have taught as a teacher-directed unit."*

The inquiry problem afforded Mr Matthews opportunities to vary the level of teacher direction provided to different groups of students that was responsive to their preferred ways of learning. A more open inquiry was tailored for students who were ready for higher levels of self-direction, while more teacher direction was provided for those who required additional guidance:

> *"[For] those students who needed my direction and help, I had scientific knowledge that was well suited to directing them and giving them explanations that they understood. The upper group, they didn't need that explanation from me because they could go out and investigate it and learn about the terms themselves…The solar vehicle initially was hands-on construction [which] had everybody engaged [Figure 1]…they could take their own construction and then go ahead and research some different aspects of solar energy. The ones that were into it and ready to use the laptops in the classroom could have my focus…Then I could go back and pick up the students who by that stage had tested everything they could possibly test about solar vehicles…'Okay, well now we need to start to work on your PowerPoint presentation'. They were photographing and videoing."*

Figure 1: Examples of solar vehicles designed and constructed in Mr Matthews' class.

When Mr Matthews was asked to compare the science in which his class engaged during the Challenge compared to previous science units, he commented that the more prescriptive approach adopted in prior units did not challenge students fully nor provide enough opportunities to promote higher-order thinking:

> *"[In] Term 1 and 2, [we did] a lot of 'We're going to do a simple experiment for a minute or two and rotate around to 12 experiments in an hour and then we might have a test on that'. It was adequate…and the results I was seeing from the simple*

experiments in the classrooms [were] good but there were quite a few students who I didn't feel were really achieving to their potential…We were pushing through so many little skills or different topics that we never got to engage in that higher level of thinking that the open-ended investigation where they're directing their own learning and you are there to sort of assist them in the room."

This view was supported by analysis of the end-of-project student survey data. When asked to compare the science they did in Term 3 with the science they did in Term 2, the majority of students reported that they completed more experiments, experienced greater ownership of the inquiry process, used their own explanations and conclusions more frequently, and participated in more in-class science discussions (Table 1). Students were interested and enjoyed science during the term, and a major reason for their interest and enjoyment is likely to be linked to the scientific approach adopted by teachers during the Challenge.

At interview, Mr Matthews articulated a proposed transformation to his classroom pedagogy arising from his experience of the Challenge; specifically, he planned to include more student-centered and open-type investigations in his future practice:

"If I could do a unit like that every term then that would be what I would do. I really liked the idea that they could go and test and create and implement that into science. I can definitely see Term 1, Term 2 and Term 3 next year adopting these scientific investigations."

The Young Science Ambassadors: A Transformative Experience for Students

A key feature of the Challenge was the involvement of the YSAs. These post-graduate scientists worked with students and their teachers in class. In Mr Matthews' class, the YSAs were also involved in the judging of the student presentations. At interview, he explained that he was very impressed with the involvement of the scientists in the Challenge, and described their role in the classroom:

"I really thought my Science Ambassadors were fantastic… Mike [YSA] spent the day discussing design aspects and really working individually with pairs to help them with their construction ideas, so he was excellent…They came back when the pairs were ready to do

Table 1: Students' views on how often they experienced different learning activities in Science in Term 3 compared with Term 2 (N = 27) *n = 26.

ITEM	STUDENTS, N (%)				
	A LOT MORE THIS TERM	A LITTLE MORE THIS TERM	THE SAME AS TERM 2	A LITTLE LESS THIS TERM	A LOT LESS THIS TERM
Students were given opportunities to explain their ideas in their own words	14 (52)	6 (22)	7 (26)	0	0
Students wrote conclusions based experiments they conducted	14 (52)	3 (11)	9 (33)	0	1 (4)
Students designed their own experiments	12 (44)	5 (19)	6 (22)	4 (15)	0
Students chose their own investigations*	10 (38)	6 (23)	6 (23)	2 (8)	2 (8)
Students had in-class discussions about science topics	12 (44)	9 (33)	6 (22)	0	0
Students did experiments by following the instructions of the teacher	11 (41)	2 (7)	11 (41)	3 (11)	0
Students did an investigation to test out their own ideas or questions	12 (44)	6 (22)	8 (30)	0	1 (4)
The teacher used real examples of science and technology to show how school science is relevant to society	11 (41)	9 (33)	6 (22)	1 (4)	0

> *their presentations. They acted as the judges and conferred with me as to what score we were going to give the pairs."*

For the students in Mr Matthew's class, working with the YSAs supported the development of their science knowledge. They also modeled how to communicate the science of their investigations for their presentations (Figure 2), as explained by John and Mark:

> ***John:*** *"One of the Science Ambassadors told us about solar panels and how they're made. Yeah, me and Mark thought [of] making this solar panel that makes electricity and then transforms it – and then making a light globe to turn on and off, so they taught us a lot."*

> ***Mark:*** *"Well, we saw how they developed their PowerPoints [slideshows] and how we could adapt ours to look more like theirs. They explained everything in simple terms and then went a bit more scientific later on…They really helped us a lot with our presentation; the way to set it out and helped us with the knowledge that we need to know to get us to the level that we need to be for research and stuff."*

Issues to over come

- Our construction methodology did help but we had to put more thinking into it.
- The size of the motor was a overly sized which made the meccano bend out of its place.
- The wiring always came off the motor because of it hanging out of the car and getting dragged on the ground
- Use a stronger glue to stick things together

Testing and timing the vehicle

1.6v

- Tested the velocity of the solar car, to test the acceleration we differed the degree of the front axle of the vehicle to 0 degrees and measured out 5m on the ground and then recorded the car. Then divided it by 5 to get the answer of how fast the car goes (m/s). The answer that we got was 0.56m/s
- Tested how different the angle has to be for the front axle to get the car to go in a revolution in 10 sec, to test this we first started off with an acute angle for the front axle of 20 degrees and tested how long it would take to go around in a circle, it took 4.65sec. So we tried......

Table of wheel angle of solar powered vehicle and time for one revolution

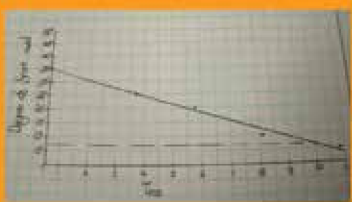
Voltage	Angle	Time
1.6	20	4.65
1.6	10	5.45
1.6	5	9.80

We have kept all of the other variables the same and changed the angle of axle to get the target time (10sec)

Table of wheel angle of solar powered vehicle and average time for one revolution

Degree of front axel	Test 1	Test 2	Test 3	Test 4	Average
25	3.62	3.78	3.51	3.49	3.6
20	5.53	5.59	5.78	5.91	5.78
10	8.19	8.54	7.97	7.94	8.16
5	11.22	11.09	11.09	10.13	10.88

Graph of wheel angle of solar powered vehicle and time for one revolution



7.75 degrees would get us a revolution in 10 seconds

Figure 2: An excerpt from the slideshow presentation devised by Mark, Jane, John and Rebecca for their student forum day presentation, illustrating some of their planning, research and results.

For Mark, working with the YSAs also broadened his view of what science and engaging in science entailed:

> *"It was important that they showed us that it isn't just all about working out math and how particles meet and all that; it's also about finding out stuff that is dangerous, and getting yourself involved and ready, and out of your comfort zone…I learned that it [science] requires a fair bit of teamwork. You've got to all put in 100 per cent, otherwise you don't get 100 per cent…there's science in everything. Everything's part of science."*

The Student Presentations: Transformations for Mr Matthews and his Students

The students presented their methodologies and research findings to two different audiences before the final student forum. Pairs of students presented their findings to the rest of the class two weeks prior to the inter-school finals. The top two pairs were combined by Mr Matthews to form a four-member team to represent the class. The finalists presented their work to a Year 6 class prior to their involvement in the forum.

For students, the culminating presentations were most frequently cited in the end-of-project survey as being the most enjoyable aspect of the Challenge. During the focus group interview, Rebecca and Mark expressed their enjoyment of presenting to a new audience:

> ***Rebecca:*** *"I think it was probably the best task I've ever done this year in science as we got to meet different people from different schools and see how they did it with their PowerPoint and it was just fun, really fun."*

> ***Mark:*** *"It felt new and fresh; being somewhere else than just doing it in the classroom, and presenting it to people that you didn't know. As well, it felt better than in the classroom because…they're [the audience] only five meters away, and you didn't have to have palm cards because the computer was right in front of you."*

For these students, the forum day presentations provided an opportunity to meet new people and to see how other students approached the problem and presentations. The chance to present to a new audience in a setting outside the classroom was also memorable. As a result, Mr Matthews explained at interview that he intended to adopt the format of the forum day presentations (i.e. students presenting, critiquing and defending their methodologies and findings) as an assessment strategy.

DISCUSSION AND IMPLICATIONS FOR CLASSROOM PRACTICE

The findings presented in this paper highlight the value of positive early engagement with science as an approach to target STEM participation. Evidence from the case study showed that the key aspects of the Challenge—the open inquiry afforded by the student research project, the student presentations and access to practicing scientists—had positive outcomes for both Mr Matthews and his students. Analysis of interview and survey data showed that students reported more positive attitudes towards science and improved depth of science knowledge and understanding, while Mr Matthews' reported increased confidence in developing students' science inquiry skills. These findings are in-line with previous studies that have demonstrated improvements in student learning and interest in science when they participate in authentic inquiry activities that require them to construct and organise knowledge, and communicate findings effectively (Hackling, Peers, & Prain, 2007; Hubber, Darby, & Tytler, 2010). In addition, the data elicited from the case study, whilst limited in its scope, allows for some reflections on the implementation of an inquiry-based approach to engage students in science learning.

Our findings illustrate the transformative potential of science inquiry in the classroom. Interviews with the students and Mr Matthews suggest that the Challenge resulted in a transformation in the enactment of science lessons in the classroom, whereby students were afforded opportunities to contribute to the development of the research project, and the teacher adapted his teaching strategies to facilitate a more student-centric approach. Our findings showed that the open inquiry-based challenge facilitated a process of guided participation, which allowed students to be active inquirers, and the teacher, with the support of the YSAs, to be an active guide (see also, Polman & Pea, 2000). While the Challenge created a transformative space to support students' move from participation in teacher-led school science to making a shared contribution to their science learning, Mr Matthews also explained how he was able to vary the 'openness' of the inquiry by facilitating different levels of student-direction as the unit unfolded. Indeed, a United States report on inquiry and the National Science Education standards (Olson & Loucks-Horsley, 2000) advocates a flexible approach to classroom inquiry that ranges from 'guided' teacher-led to more 'open' learner-directed (see Table 2), depending on the learning context.

They argue that:

> *…experiences that vary in openness are needed to develop inquiry ability. Guided inquiry can best focus learning on the development of particular science concepts. More open inquiry will afford the best opportunities for cognitive development and scientific reasoning (p. 30).*

Evidence from our case study suggests that the format adopted by the Challenge presents one approach for developing students' science inquiry that can create space for different levels of student ownership and teacher-direction that is responsive to students' learning needs.

The inclusion of the student forum presentations motivated and focused students on presenting their findings to different audiences. A small number

Table 2: Essential features of classroom inquiry and their variations (Olson & Loucks-Horsley, 2000, p. 29).

ESSENTIAL FEATURE	VARIATIONS			
1. Learner engages in scientifically orientated questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyse	Learner given data and told how to analyse
3. Learner formulates explanations from evidence	Learner formulates explanations after summarising evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication
More ←	Amount of learner self-direction			→ Less
Less ←	Amount of direction from teacher or material			→ More

of students travelled to Townsville to present their projects to other participant students, teachers, scientists and science education stakeholders in attendance. This model limited the number of students that could participate in the finals to four students per school. Given the benefits and enjoyment identified by the study participants when they presented to different audiences, we urge organisers of similar events to consider the use of information and communication technology, such as a dedicated YouTube™ channel, to enable more students to participate in the critique of other students' work and to receive feedback on their own.

The involvement of the YSAs provided students with opportunities to interact with positive scientist role models. Students reported trust in the science knowledge and presentation skills of the Ambassadors, and valued their contribution to the students' understanding of science. These benefits arose from the YSAs' direct involvement in the classroom: students could tap into the Ambassadors' science knowledge, and a comfortable space was afforded for the Ambassadors to interact with the students in the context of their inquiry. A key strength of the Challenge format was that the YSAs did not require specific knowledge of the Queensland science curriculum or access to scientific instrumentation to enable the research; they contributed meaningfully by working directly with student groups. This approach differs from other scientist-student arrangements where, for example, students research aspects of the scientists' work (Oliver et al., 2011; Howitt, Lewis, & Waugh, 2009) or the scientist-student partnership is limited to extracurricular activities (for a review see Sadler et al., 2010). It also avoids problems that may occur when teachers and early-career scientists are not sure of the best approach to involve the scientist in the classroom (Keys, 2008).

Notwithstanding the positive outcomes that can arise from engaging students in authentic inquiry-based science, this endeavour may prove challenging for teachers as it requires "a new set of teaching and learning skills that give more agency to students" (Tytler, 2007, p. 60). The importance of primary teachers' self-efficacy for guiding student inquiry, in particular, is well documented within the literature (e.g., Gunning, & Mensah, 2011; Lumpe, Czerniak, Haney, & Beltyukova, 2012). Teachers' self-efficacy can be improved through the provision of good quality pre-service and in-service teacher education programs, and ongoing expert advice and support (Lokan, Hollingsworth, & Hackling, 2006; Masters, 2009). In the context of the Challenge, a full-day professional development workshop helped to prepare teachers by focusing on the implementation of science inquiry and the development of students' science inquiry skills. The YSAs were also important partners in the inquiry process and provided necessary ongoing advice and support. For teachers who may not be confident in implementing inquiry-based projects, Mr Matthews' experience reminds us that increasing students' ownership of their learning reduces the onus on teachers to be the providers of knowledge, which, in itself, can be an empowering and transformative experience: "…there was a lot more science covered through the investigations and critiquing the presentations than I could possibly have taught as a teacher-directed unit" (Mr Matthews).

CONCLUSION

This paper highlights one approach to implementing more open science inquiry in the classroom. The key features of the Wonder of Science Challenge created a transformative space that impacted positively on Mr Matthews' self-efficacy and attitudes toward science teaching, and on his students' depth of science learning, interest and engagement. While teachers' lack of self-efficacy for facilitating more open science inquiry can be a barrier to the implementation of such approaches, the research findings reported herein highlight how providing students with greater self-direction, linking with scientists in meaningful ways, and affording students the opportunity to present, critique and defend their methodologies and findings to a broader audience can support and extend student learning in ways that can be empowering for teachers.

REFERENCES

Ainley, J., Kos, J., & Nicholas, M. (2008). Participation in science, mathematics and technology in Australian education (ACER Research Monograph 63). Retrieved from http://www.acer.edu.au/documents/mono63_mathsscitechsept08.pdf

Aikenhead, G. S. (2005). *Science education for everyday life: Evidence-based practice.* New York and London: Teachers College Press.

ATSE, Queensland Division. (2012). *The Wonder of Science Business Plan 2011–2014.* Melbourne: ATSE.

ACARA. (n.d.). *The Australian Curriculum: Science, Foundation to Year 10 Curriculum.* Retrieved April 29, 2012, from: http://www.australiancurriculum.edu.au/Science/Curriculum/F-10

Barmby, P., Kind, P. M., & Jones, K. (2008). Examining changing attitudes in secondary school science. *International Journal of Science Education,* 30(8), 1075–1093.

Enochs, L., & Riggs, I. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics,* 90, 694–706.

Fensham, P. (2006). *Research and boosting science learning: Diagnosis and potential solutions. In 2006—Boosting Science Learning—What will it take?* Proceedings of the ACER Research Conference, Hyatt Hotel, Canberra 13–15 August 2006 (pp. 70–73). Retrieved from http://www.acer.edu.au/research_conferences/2006.html

Gunning, A. M., & Mensah, F. M. (2011). Preservice elementary teachers' development of self-efficacy and confidence to teach science: A case study. *Journal of Science Teacher Education,* 22(2), 171–185.

Hackling, M. W., Goodrum, D., & Rennie, L. J. (2001). The state of science in Australian secondary schools. *Australian Science Teachers' Journal,* 47(4), 6–17.

Hackling, M, Peers, S., & Prain, V. (2007) Primary Connections: Reforming science teaching in Australian primary Schools. *Teaching Science* 55(3), 12–17.

Harris, K.-L., & Farrell, K. (2007). The science shortfall: An analysis of the shortage of suitably qualified science teachers in Australian schools and the policy implications for universities. *Journal of Higher Education Policy and Management,* 29(2), 159–171.

Howitt, C., Lewis, S. W., & Waugh, S. (2009). Analysis of an exemplary scientists in schools project in forensic science: Collaboration, communication and enthusiasm. *Teaching Science*, 55(3), 46–51.

Hubber, P., Darby, L., & Tytler, R. (2010). Student outcomes from engaging in open science investigations. *Teaching Science,* 56(4), 8–12.

Keys, P. M. (2008). The role of early career scientists working in the classroom. Teaching Science, 54(3), 49–51.

Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education,* 34(2), 153–166.

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education,* 28(6), 591–614.

Lyons, T., & Quinn, F. (2010). *Choosing Science: Understanding the declines in senior high school science enrolments.* (Research report to the Australian Science Teachers Association). Retrieved from http://www.une.edu.au/simerr/pages/projects/131choosingscience.php

Lokan, J., Hollingsworth, H., & Hackling, M. (2006). *Teaching science in Australia: Results from the TIMSS 1999 video study.* Camberwell, Victoria: Australian Council for Educational Research.

Masters, G. N. (2009). *A shared challenge: Improving literacy, numeracy and science learning in Queensland primary schools.* Canberra, Australia: Australian Council for Educational Research (ACER).

Murphy, C., & Beggs, J. (2005). *Primary Science in the UK: A Scoping Study.* Final Report to the Wellcome Trust. London: Wellcome Trust.

OECD. (2005). *Student questionnaire for PISA 2006.* Paris: OECD Publications.

OECD. (2006). *Assessing scientific, reading and mathematical literacy: A framework for PISA 2006.* Paris: OECD.

OECD. (2012). *Education at a Glance 2012: OECD Indicators.* Retrieved from http://dx.doi.org/10.1787/eag-2012-en

Office of the Chief Scientist. (2012). *Health of Australian Science.* Canberra: Australian Government.

Oliver, R., Rybak, K., Gruber, C., Nicholls, G., Roberts, G., Mengler, J., & Oliver, M. (2011). Increasing engagement in science through an authentic crop protection experiment for Year 9 school students working with scientists. *Teaching Science*, 57(3), 13–18.

Olson, S., & Loucks-Horsley, S. (2000). I*nquiry and the National Science Education Standards: A Guide for Teaching and Learning.* Retrieved from http://www.nap.edu/catalog/9596.html

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education,* 25(9),1049–1079.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage.

QSR International. (2012). *NVivo (Version 10)* [qualitative data analysis software]. Doncaster, Australia: QSR International. Retrieved from http://www.qsrinternational.com

Polman, J.L., & Pea, R.D. (2000). Transformative communication as a cultural tool for guiding inquiry science. *Science Education,* 85, 223–238.

Sadler, T. D., Burgin, S., McKinner, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching,* 47(3), 235–256.

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future.* Camberwell, Australia: ACER Press. Retrieved from http://www.acer.edu.au/documents/AER51_ReimaginingSciEdu.pdf

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps, J. (2008). *A review of the literature concerning supports and barriers to science, technology, engineering and mathematics engagement at primary-secondary transition.* Retrieved from http://www.innovation.gov.au/Skills/ResourcesAndPublications/Documents/OpenPathinSciTechMathEnginPrimSecSchTrans.doc

Dr Louisa Tomas *is a senior lecturer in the School of Education at James Cook University. She is currently researching pedagogical approaches that engage students with socioscientific issues, and the role of students' emotions in this context.*

Dr Cliff Jackson *is a lecturer in the School of Education at JCU. He is currently researching the use of classroom profiling training in teacher education.*

Dr Karen Carlisle *is a researcher and tutor in the School of Education at JCU. Her research interests include coteaching in science classrooms as a mechanism to enhance the teaching and learning experience for teachers and students.*