KATHRYN PAIGE, YVONNE ZEEGERS, DAVID LLOYD and PHILIP ROETMAN

RESEARCHING THE EFFECTIVENESS OF A SCIENCE PROFESSIONAL LEARNING PROGRAMME USING A PROPOSED CURRICULUM FRAMEWORK FOR SCHOOLS: A CASE STUDY

Received: 2 May 2014; Accepted: 30 July 2014

ABSTRACT. This paper reports on an action research-based professional learning programme (PLP) in which early career teachers volunteered to identify and then research an aspect of their science teaching practice. The PLP was facilitated by academics from the School of Education and the Barbara Hardy Institute at the University of South Australia. The teachers, who worked in low socio-economic areas of Adelaide's northern suburbs, participated in the programme in order to enhance their pedagogical content knowledge about science. They also shared an interest in connecting their students to the natural world through citizen science. The PLP utilised collaborative practices and engagement within a socio-constructivist pedagogical framework. As a result of their participation, the teachers reported increased confidence to plan and teach units of work that moved away from textbook-orientated approaches to science. Teachers were interviewed at key points during the PLP, and transcripts were analysed against Tytler's (*Re-imagining science education*: *Engaging students in science for Australia*'*s future*. Camberwell, Victoria: ACER Press, 2007) proposed curriculum framework for science. This case study identified teacher learning, and the strengths and limitations of the PLP, thus enabling the facilitators to reflect on the programme.

KEYWORDS: action research, citizen science, collaborative learning, content analysis, curriculum, school science, teacher professional learning

INTRODUCTION

This paper reports on one aspect of a 3-year professional learning programme (PLP) designed to support early career teachers as they developed their pedagogy in inquiry-based science. Data was collected from three teachers who, as part of the PLP, used a citizen science project to engage their students in meaningful science in a social context. The outcomes of the PLP were analysed against Tytler's proposed science curriculum framework for a "re-imagined science curriculum" (2007, p. 64). While the main purpose of Tytler's framework is to scaffold science curriculum development within schools, we found this framework useful for examining the professional learning of teachers as they engaged in developing and delivering the science curriculum. By analysing the PLP against Tytler's framework, we were able to both critique the comprehensiveness of the PLP, and identify possible extensions to the framework. This process has led us to reflect on the value of our PLP and on curriculum development.

This paper addresses three aspects of the PLP. First, it identifies the achievements and continuing needs of the participating teachers with respect to their own content knowledge, their science pedagogy and their assessment of student learning outcomes. Second, it considers the effectiveness of the innovative aspects of the PLP, including the use of citizen science and the focus on raising students' educational aspirations. Third, it posits that factors in the success of the PLP included the relatively long-term nature of the programme, the willingness of the teachers to genuinely reflect on and address their needs, and the ongoing financial and professional support offered by the researchers to the teachers.

This case study investigates whether the PLP reflects the recommendations of current leaders in science education. The two research questions are:

1. Is the curriculum framework for science proposed by Tytler (2007) a useful vehicle for analysing teachers' practices and identifying their needs?
2. What are the strengths and limitations of the PLP?

Context of the Case Study

In 2010, the University of South Australia was awarded funding by the Department of Education and Workplace Relations to improve outreach programmes to primary and secondary schools in the northern suburbs of Adelaide, in an area of socio-economic disadvantage. The School of Education, in collaboration with the Department for Education and Child Development, received some of this funding to establish the Aspirations Project. This 3-year initiative involved university academics and school teachers working together to promote excellence in school curriculum development and delivery. The ultimate aim was to raise students' educational aspirations and, eventually, tertiary participation.

As part of the curriculum development and delivery focus, 30 teachers participated in action research projects to develop and evaluate aspects of their own pedagogy. In order to cater for different aspects of the school curriculum, four Action Research Networks (ARNs) were established

(*Citizen Science*; *Engagement and Wellbeing*; *ICT and Literacy*; *Reading, Parents and the Early Years*). Participating teachers selected an ARN appropriate to their interests and worked on professional learning projects that strengthened their capacity to offer their students learning experiences that were both intellectually demanding and supportive of success. The academics, who were mainly teacher educators, developed appropriate professional learning programmes for the teachers in order to provide them with the support and guidance they needed to achieve these aims. Each ARN held regular meetings throughout the year. In addition, all ARNs—teachers and academics—came together for a full day each term. The day commenced with guest speakers providing insights into various relevant topics, including educating adolescents (Hayes, Mills, Christie, & Lingard, 2006) and using student life worlds to develop innovative curriculum programmes (Moll, Amanti, Neff, & Gonzalez, 1992). The rest of the day was spent in the individual ARN teams developing the teachers' action research projects. The teachers reported the outcomes of their action research projects at a conference at the end of each year.

This paper describes the process and outcomes of the Citizen Science ARN, so called because the PLP was based around a series of citizen science initiatives called 'Operations'—in this case 'Operation Spider' (aspects previously reported in Paige, Lloyd, Zeegers, Roetman, Daniels Hoekman, Linnell et al., 2012; Zeegers, Paige, Lloyd & Roetman, 2012; Zeegers & McKinnon, 2012; Roetman, 2013; Roetman & Daniels, 2011).

The progress of three early career teachers in the Citizen Science ARN, one secondary and two primary, was followed over 2 years. These teachers wanted to improve their confidence in teaching science and become more innovative in their teaching practice. To do this, they collaborated with four academics (three teacher educators from the School of Education and an ecologist from the Barbara Hardy Institute).

The PLP focused on developing teachers' confidence to plan a unit of work that would connect students to their local natural world (Coertjens, Boeve-de Pauw, Maeyer & Petegem, 2010). In the first year, the work was centred on the theme of spiders. The academic team developed comprehensive teaching resources that were accessible from the Barbara Hardy Institute (http://w3.unisa.edu.au/barbarahardy/teachers/spider.asp). These resources included a suggested lesson sequence which could be adapted to a range of year levels, information about spiders, links to relevant multimedia and links to the national science curriculum. The teachers reported that these resources became invaluable in the development of their science programme which was designed as an integrated unit of work.

Professional Learning Model

The pedagogical approach to teacher professional learning that was used in this study was based on well-theorised foundations and has been informed by decades of our team working with teachers who lack confidence in teaching science. Contemporary science pedagogy reflects the importance of planning meaningful, sequential, and learner-focused experiences based on constructivist principles where teachers collaborate with their students in order to create meaning in ways that students can make their own (Riddle, 1999). The use of teaching and learning models such as the 5Es (Bybee, 1997; Australian Academy of Science, 2010) or an Interactive Teaching Sequence (Faire & Cosgrove, 1993) provides primary and middle years teachers with a framework for constructing sequential and developmental units of work that build on students' prior knowledge. In the Citizen Science ARN, our approach to professional learning has been to model this practice. This involved establishing and building upon the expertise and experiences of teacher participants who already came with a range of teaching strategies and pedagogical content knowledge (not necessarily just in science), and assisting them to evaluate their own pedagogy and beliefs about student learning.

As such, and in accordance with a constructivist perspective, the first steps in developing an appropriate professional learning experience was to meet the participating teachers, gain an understanding of their backgrounds, and establish what they aimed to achieve. Using this information, we conducted an interactive workshop during which we discussed our professional learning model, provided a background to citizen science, and modelled pedagogically challenging and engaging practical experiences with spiders which could be adapted and applied by the teachers in their own classrooms. The workshop was designed to provide these early career teachers with the additional confidence and capacity to independently plan contextually based, sequential and practical learning experiences which would contribute to meaningful learning, rather than relying on prescribed textbook content and methods.

As part of the Citizen Science ARN and our PLP, the teachers identified and then researched an aspect of their pedagogy using action research methods (Mamlok-Naaman & Eilks, 2012).

Team meetings were held in the schools twice each term, enabling the teachers and academics to share practices, ideas and outcomes and to build professional relationships based on mutual respect. These meetings provided planning time and access to a wide range of resources, including the Barbara Hardy Institute Website. During meetings, each teacher was mentored by an academic who assisted them to generate, clarify and refine their action research questions, and to plan the collection and analysis of data. The academic staff further supported the teachers by visiting their schools on request, attending class field trips, and hosting interactive science workshops on the university campus with their students. In addition, the teachers presented the outcomes of their action research projects to the University's Aspirations Project Annual Conference and at the state science conference. Their work also contributed to journal articles (Paige et al., 2012).

Literature and Links to Curriculum Framework

In this section, we briefly describe three areas of the literature that have informed this study: citizen science, links to the Australian Curriculum, and teacher professional learning.

Citizen Science

Citizen Science is a term used to describe projects that involve collaboration between scientists and the wider community, typically involving research, education, and community engagement (Roetman & Daniels, 2011). The community-focused Operation Spider project, for example, was designed to collect research data about South Australian spider species, and to gain a greater understanding of how people interact with spiders. Participants were recruited via community engagement activities (through radio, newspaper, education programmes and social media). Scientists provided resources (e.g. fact sheets) which helped the community to learn more about spiders and their habitats in the local environment. Based on their observations, participants could also submit data to a spider survey. This citizen science project therefore had both scientific and educational goals.

Although most published work on citizen science and education (e.g. Bonney, Ballard, Jordan, McCallie, Phillips, Shirk, & Wilderman, 2009) has focussed on Informal Science Education (Zoellick, Nelson, & Schauffler, 2012), many citizen science projects are designed for schools (Trautmann, Shirk, Fee & Krasny, 2012). There are several advantages to incorporating citizen science projects into the school environment. Notably, scientists benefit when teachers and students collect data (Tinker, 1997), and both teachers and students find the collection and use of real data highly engaging (Berkowitz, 1997; Moss, Abrams &

Kull, 1998; Trautmann et al., 2012). The PLP described in this paper purposefully linked to a citizen science project on spiders with the action research project in order to support early career teachers and engage their students with science in a meaningful context.

Links to the Australian Curriculum

In December 2008, all Australian state, territory and commonwealth education ministers agreed to the introduction of a national curriculum. Since then, the Australian Curriculum has been developed in stages in collaboration with a wide range of stakeholders including teachers, principals, governments, state and territory education authorities, professional education associations, community groups and the general public (ACARA, 2013). The curriculum will ultimately cover Foundation to Year 12, and incorporates three key components that teachers should address in their learning programmes: *Curriculum Learning Areas*, *General Capabilities*, and *Cross-Curriculum Priorities*. Our PLP aligned with elements of each of these key components.

The Science Curriculum Learning Area is divided into three strands: *Science Understanding* (the important science concepts from across different areas of the discipline); *Science as Human Endeavour* (the nature and influence of science) and *Science Inquiry Skills* (skills essential for working scientifically). In our PLP, Science Understanding was primarily based on the biological science sub-strand with a focus on the key ideas about living things. The emphasis was on spiders, their life cycles, anatomy, adaptations, habitat and classification. The strand Science as Human Endeavour was addressed by taking science outside of the classroom to collect data and develop understanding about physical characteristics of spiders and their habitats. Science Inquiry Skills involved the key skills of questioning and predicting, planning and conducting, collecting, processing and analysing data and evaluating and communicating findings.

In the Australian Curriculum, General Capabilities include literacy, numeracy, ICT competence, critical and creative thinking, ethical understanding, personal and social competence and intercultural understanding. Four of these General Capabilities were addressed through our PLP: critical and creative thinking, personal and social capability, ethical understanding and numeracy.

The three Cross-Curriculum Priorities in the Australian Curriculum are Aboriginal and Torres Strait Islander histories and cultures, Asia and Australia's engagement with Asia and Sustainability. Our PLP specifically addressed the Sustainability priority of “authentic contexts for exploring, investigating and understanding science” (ACARA, 2013, Cross curriculum priorities overview, para 4)). The PLP supports this priority by providing students living in the northern suburbs of Adelaide, an area of socio-economic disadvantage, with opportunities to explore, investigate and connect to the natural world.

Teacher Professional Learning

While this PLP focused on citizen science, the intent of any science PLP should be to enable teachers to apply the pedagogy to their entire science programme, and perhaps even to other learning areas. As Tytler, Symington & Smith (2011, p.37) comment, “this places teacher professional learning at the very centre of what can be gained from such programs”. Thus organising regular and developmental professional learning sessions that build upon teachers’ backgrounds, needs and interests such as this PLP, are critical to its success (Rogers, Abell, Lannin, Wang, Musikul, Barker & Dingman, 2007).

This feature of our current and previous PLP projects has evolved over many years in response to the needs and wants of systemic requirements and, most particularly, to those of teachers (Kinna & Paige, 2010; Paige, Lawes, Matejcic, Taylor, Stewart, Lloyd et al., 2010; Prosser, Reid, & Lucas, 2010; Wilson & Lloyd, 2010). As Cornish & Jenkins (2012, p. 160) note, early career teachers only develop a desire to master their content knowledge and improve their teaching skills once they have come to terms with managing the daily classroom routines and have adjusted to their identity as a teacher. Thus, in order to help these early career teachers explore their professional identity, we encouraged them to share their own research, planning and trialling of different pedagogical strategies, and to seek advice about further strategies. As well as sharing resources and materials, the teachers were encouraged to identify their conceptual science needs, which we then addressed in subsequent meetings. The meetings were conducted in a range of settings, including the teachers’ schools, and the university campus.

The PLP approach we developed for this ARN was compatible with the South Australian state school’s authority’s *Teaching for Effective Learning Framework* (Department of Education and Children’s Services, 2010) through which the teachers are encouraged to assist their students to develop metacognitive thinking skills; to develop deep learning about the particular science topic, to use a pedagogical approach which built upon their learners’ understandings, to connect the learning to the students' lives and aspirations and to assess students' learning using authentic contexts. The teachers were encouraged to value student dialogue as a means of learning, and to help learners apply their learning to other contexts, particularly by communicating their understandings using multi-modal representations (Waldrip, Prain & Carolan, 2010).

Connections Between the plp and the Proposed Curriculum Framework for Schools

An impressive range of literature argues that science learning needs to be more than just the mastery of conceptual frameworks of science content such as Newtonian mechanics, mineral classification, ecosystems and the periodic table of elements. This literature aligns with Tytler's (2007) call for a re-imagined curriculum. Science learning needs to be embedded in contexts that include learning for social and eco-justice (Bowers, 2001, 2006), socio-political action (Roth & Désautels, 2002), sustainable living (Murray, Cawthorne, Dey & Angrew, 2012) and the ecosystems in which students live (Dickinson & Bonney, 2012). The context in which science is placed is important for its learning and for its application by students in the world in which they live and will very soon manage. The proposed curriculum framework argues for such an approach to science, suggesting that, if deep learning is to occur and if it is to be of value to students and the community, it must be contextualised in community and authentic in its application.

In the last three decades or more, science educators in the Western world have come to recognise the importance of the social and cultural context in which learning occurs (Bowers, 2001, 2006; Cobern, 1993, 1994; Hodson, 1993; Matthews, 2009). Various pedagogical approaches have endeavoured to embed science learning in the context of students' life worlds. These approaches include *science, technology, society and the environment* (Pedretti, 1997; Solomon & Aikenhead, 1994), *the history, philosophy and sociology of science* (Matthews, 1992), *science for sociopolitical action* (Hodson, 2003; Roth & Désautels, 2002), *science for all* (Fensham, 2003; Osborne, 2006), *science using everyday contexts* (Kim, Yoon, Ji & Song, 2012) and *science and sustainability* (Paige & Lloyd, 2011, 2012; Clark & Zeegers, 2012). Despite these efforts, as Tytler (2007) reports,

> The broad shape of science education has remained relatively unchanged, at least in its official guise, for the last half-century … the emphasis is on conceptual knowledge, compartmentalised into disciplinary strands, the use of key, abstract concepts to interpret and explain relatively standard problems, the treatment of context as mainly subsidiary to concepts, and the use of practical work to illustrate principles and practices. (p. 3)

This concern for the shape of science education led to a reform agenda which was presented at the 2006 Australian Council for Educational Research (ACER) Conference. The conference included three keynote papers (Osborne, 2006; Rennie, 2006; Bybee, 2006) and numerous other presentations. Based on these presentations, a review was undertaken and a report developed: *Re-imagining science education*: *Engaging students in science for Australia*'*s future* (Tytler, 2007). The report regards science learning "as an active, adaptive process rather than a pathway to resolved conceptual end points, where the literacies, or discursive elements of science are an important focus, and where values, aesthetics and narrative are given due emphasis" (Tytler, 2007, p. 63). One of the key outcomes of the report was a proposed framework for science curriculum development by schools. Eight curriculum strands are proposed in the ACER report:

- Conceptual content and context
- Pedagogy
- The way science works
- Investigative science
- Capabilities relating to science
- The setting of school science
- Assessment analysis
- Teacher learning.

The potential impact of this reform agenda and its proposal for curriculum development lead us to consider analysing our PLP against this curriculum framework. It also underpinned our belief that "The content of science needs to be set within contexts that are meaningful to students and cater for their interests; science [should be] introduced on a need-to-know basis and structured so that major ideas of science are introduced" (strand one, Tytler, 2007, p. 64). Thus, the eight strands provided the analytical framework for the PLP discussed in paper.

Method (Data Collection and Analysis)

The case study focused on three teachers who had participated in the PLP for 2 years. These early career teachers (two primary, one male and one female and one secondary, male), were in either their third or fourth year of teaching. All three teachers' initial education degree had a minor or sub-major in science reflecting their expertise and previous experience in the field. One teacher worked in a year 8/9 setting (13–14 year olds) as a specialist science and mathematics teacher and the other two were generalist primary teachers with year 4 and year 5/6 classes (9–11 year olds). These three educators were keen to develop their expertise in teaching in complex, low socioeconomic school settings and participated enthusiastically in the PLP. Semi-structured interviews based on the research questions were conducted with each teacher. The interviews varied between 45 min and an hour and focused on the teachers' views of the PLP, their experiences as early career teachers, science pedagogy, teacher background and confidence, and the value of the project. Audio-recordings of the interviews were transcribed in preparation for analysis.

A content analysis was conducted incorporating techniques described by Ritchie and Spencer (1994). First, data were sorted for key themes. A priori themes were identified using the eight strands proposed by Tytler (2007, p. 64) as listed above. Sub-themes were then developed using Tytler's comments on each strand (Appendix). Emergent themes, not described in Tytler's framework, were also identified. Data were then filtered through a third step that Ritchie & Spencer (1994) term 'mapping and interpretation', wherein we described, defined and provided explanations for each theme. While the themes drawn from the proposed curriculum framework were pre-defined, the emergent themes required definitions. Once we had discussed and clearly defined each theme, the final step was to then reflect on the extent to which the PLP had, or had not, addressed the eight strands of the proposed curriculum framework. This analysis enabled us to identify elements that would require much greater attention in the planning and delivery of future PLP projects.

Findings

The data analysis explored the alignment of the PLP (or lack thereof) with the recommendations of school science curriculum experts. In the following analysis, the three teachers are identified as Teacher 1 (T1), Teacher 2 (T2) and Teacher 3 (T3). T1 was a middle school/secondary teacher, T2 was a middle primary teacher and T3 was upper primary teacher. While the interviews focused on the teachers' professional learning, the teachers often made reference to student learning as evidence of recognition of their own professional growth. Table 1 provides an overview of the number of teachers' comments as categorised against the proposed curriculum framework strands. Each strand is then elaborated upon with evidence to support the findings.

TABLE 1

Number of comments coded by Tytler's (2007) curriculum framework strands

Strand Name	*Number of comments*
1 Conceptual content and context	85
2 Pedagogy	56
3 The way science works	22
4 Investigative science	7
5 Capabilities relating to science	21
6 The setting of school science	9
7 Assessment analysis	11
8 Teacher learning	46

Strand 1: Conceptual Content and Context (85 Comments)

A fundamental aspect of science learning by students is the development of conceptual frameworks or schema through which they can make sense of the natural world. This conceptual development is considerably enhanced when students' interests are catered for in familiar and motivating settings. In this project, the study of spiders motivated students to the point where they evidently enjoyed coming to school, were excited about doing homework in their backyards and students "who normally refuse to do any homework at all were bringing spiders to school in jars with labels on them so they were obviously spending their time at home looking for spiders" (T1). Students' enthusiasm for the topic of spiders drove the topic and "changed the focus of the unit" (T1), leading to considerable conceptual and affective learning. Because students brought in so many unfamiliar spiders, the class "actually went into a bit of classification and then looking at local spiders" and "it actually changed where I was sort of going" (T1); students took charge of the curriculum. The teachers reported that by eliciting and valuing student interests, topics naturally developed or emerged—students had input into the curriculum. There was also evidence that students developed affectively. They demonstrated an appreciation of the natural world and, in particular, spiders. Spiders were understood and appreciated as being both fascinating and an important part of the ecosystem. Students demonstrated a connection to the life world of spiders through their extended studies at home, sometimes with their parents. For many, fear of spiders changed to admiration. Connecting with the environment meant learning occurred at greater depth. One of the participating teachers reported that, by the end of it, they knew that spiders were good because they controlled pests … they didn't realise how many different spiders there are … by the end, they were able to name six or seven spiders that they could find around the place. (T1)

Strand 2: Pedagogy (56 Comments)

The teachers' practices involved a wide range of pedagogies, the second strand identified by Tytler. Key themes to emerge in this strand included using frameworks to plan, learning in the outdoors, using ICTs, curriculum integration, hands on experiences and assessment for diversity. The first key theme to emerge from the interviews was the importance of having a framework to assist planning. As part of the PLP, the Interactive Teaching Sequence (Faire & Cosgrove, 1993) and the 5Es (Bybee, 1997) were introduced. The importance of analysing students' prior knowledge and developing exploratory experiences to build on alternative conceptions was also emphasised. As T1 mentioned, "I focused on prior knowledge and providing exploratory experiences" (T1). Similarly, T3 found the 5E model helpful in sequencing learning experiences: "The 5Es … just trying to work through that process".

It was clear that teachers were committed to actively involving students in their own learning. They provided examples of their students' involvement in hands on interactive experiences: "[from] drawing a spider with a head and body and legs, to drawing the cephalothorax, the abdomen, the eight-jointed legs and collecting specimen in jars" (T1) and "hiring animals from Nature Education Centre"(T3). What was evident was the focus on using scientific terminology to develop students' understanding.

The teachers found that the benefits of the learning outweighed the issues arising from taking a diverse range of students on excursions outdoors in the schoolyard or further. This is reflected in the comment about the range of places visited both outside the school:

One of the biggest differences this year has been going on excursions … [we] went to the university, museum, beach … [and we] plan to go to Para Wirra [National Park].(T2)

and inside the school grounds:

We did an aerial map of types of things that we found, different types of bushes, trees. (T3)

The teachers could see the importance of spending time outside their classroom to provide broadening experiences and many of the magical teaching moments came from these.

The use of ICTs in the classroom was also seen as an enabler to increase student knowledge and engagement. Technologies used included interactive whiteboards, YouTube clips and blogs. As T2 said:

We made a map using Google Maps, Google Earth … we went around the school using stickers, we made a key and they were mapping them on their individual maps. (T2)

Cross-curriculum experiences were provided to enhance the connectivity, reinforce concepts learnt and provide a meaningful context. Examples included Literacy, the Arts, Mathematics and ICTs. For example, T2's comment reflects a focus on literacy:

We're doing literacy, but again, it's tying into our science and something they can really relate to; something they're learning and it makes sense. (T2)

Strand 3: The way Science Works (22 Comments)

While the way science works (the epistemic aspect) and the way science contributes to society (the sociological aspect) were not comprehensively or explicitly addressed by participants in this study, it was apparent that science was being used to explore aspects of students' life worlds. As such, the science learning was modelling how the scientific processes of exploration, observation, measuring, recording, managing risk, representing and reporting can assist us to know more about the natural world. Engaging, observing and recording came through particularly strongly, as illustrated by the teacher comments:

They were identifying spiders and evidence of spiders: egg sacs, exoskeletons, trapdoor spider holes. (T2)

Lots of parents are coming up to me saying, "Thanks, now my son goes out into the backyard, we've got jars of animals, specimens, insects all over the place". They were kind of joking, they weren't really upset … [one student] filled up page with a description of how he's been observing daddy long legs behind the toilet, and reading it, I was blown away … it's like real science. He's taken it to the next level, without him really knowing. (T2)

Also strongly evident was the development of respect and wonder for the natural world. Students came to know, respect and even like spiders as illustrated in the following comment:

They really gained an appreciation of spiders, as well as learning about them, and being fascinated by them … their behaviours changed around spiders as well. So they grew a bit more of an appreciation and respect for them, as well as … all the facts. (T2)

Strand 4: Investigative Science (7 Comments)

Investigative science pedagogy was more implicit than explicit in the interviews. The teachers talked about hands on experiences and skills such as labelling, observing and classifying. However, probing was needed for the teachers to articulate this. There were only seven references to investigating through the three teacher interviews and no evidence that student questions were used to develop and carry out investigations. There was evidence that students, both primary and secondary, carried out their own investigating at home with the involvement of parents and grandparents. Setting up investigations through students' questions needs to be a stronger focus in subsequent professional development experiences.

Strand 5: Capabilities Relating to Science (21 Comments)

The teachers embedded investigative science skills—the ways of working and thinking scientifically and the nature of science—into the learning experiences they provided for their students. This strand was strongly evident in the practice of all three teachers. The students used their investigative skills in the schoolyard and in the classroom to contribute to a deeper understanding of spiders and their role in the ecosystem:

> Not just drawing, but an annotated diagram with terminology shifting towards the scientific (e.g. abdomen instead of body and the terms, cephalothorax, egg sacs). (T1)
> [The students are] now questioning and looking into things more, rather than just "Oh, there's a puddle over there" [instead] "Oh, I wonder how that got there?" … It's just those skills that they developed through year, now they're applying it to everything'. (T2)

The students were also involved in thinking and working scientifically at home and this is reflected in a parent's comment to T2, "now my son goes out into the back yard, we've got jars full of animals, specimens, insects all over the place". The positive approach to learning science led to increased attendance at school and participation in learning:

> Engagement; taking it home and doing observations and writing things down. They found a lot of stuff in the schoolyard and at home and described it scientifically. (T1)
> … curiosity and fascination with the natural world. (T2)

A shift in attitudes towards science was also noted, with teachers commenting that students' views moved "from the laboratory-based lab coat-laden stereotype to an understanding of how broad science is, different types of scientists" (T1). Another positive outcome reported is reflected in the following comment by T1: "With a more scientific understanding, kids have moved from a 'kill it' attitude to realising the importance of spiders and that spiders are not as dangerous as they previously thought". This reflects the idea that experience and understanding reduces fear and increases protection and environmental concern. Being involved in this project had an affective impact that was useful for driving cognitive learning.

Strand 6: The Setting of School Science (9 Comments)

The school science in this project was focused outside the classroom—in the home and the broader community. There were a number of references to science occurring outside the classroom, including the value of using the schoolyard, local wetlands and sites further afield, such the university, beaches and a local national park.

[A student] and his dad had the tweezers out so lots of things we've been talking about in class, they soak it up, bring it home. (T2)
So not only looking at spiders but also getting a chance to see the university, tying it all in with the Aspirations Project. (T2)
Some of the things we've been learning before we went to the beach. I made sure we did work, around like tides, and things like that, what you can find in tidal pools. (T2)
One of our main themes, this year, would have been natural environment … even palaeontology. Tying everything together, we did a unit on Para Wirra National Park. (T2)

Links between other learning areas were raised by all three teachers. The two middle school teachers working in a secondary setting focused on how the timetable impacted on integration and acknowledged how much easier it was for their primary-based colleagues. As a middle school teacher in a year 8/9 setting stated:

I don't think a lot of the kids make correlations between subjects, which in primary school, is very easy to do, you can do it, but at high school when you've got your Science and Mathematics it's quite hard. (T1)

Mathematics and literacy were readily incorporated into science and there were "Ah ha" moments for both students and teachers when they became aware of this integration.

There's so much Maths and Literacy that can be incorporated into Science anyway that a lot of teachers don't realise. (T2)
We also blended it in well with literacy so they were writing reports and I made lots of PowerPoint presentations for reading comprehension. (T2)

It is interesting to note that the implementation of units of work around transdisciplinarity was not something that was articulated by these teachers, highlighting an avenue where future professional learning could occur.

Strand 7: Assessment Analysis (11 Comments)

Assessment of learning in science is an essential and required element of planning for learning, and one to which all teachers are accustomed. The interview data revealed limited detail on how these early career teachers actually assessed student learning during their science units. This highlights the need for teacher PLPs to place a far greater emphasis on developing teachers' capabilities in assessing, recording and reporting student learning. However, this is not to say that these teachers did not assess their students' learning. In fact, they could clearly articulate authentic assessment strategies in which students represented their learning in a variety of ways, including student assembly presentations and via conferences with students:

> [They learned about] the food web and the interconnections of all living things, because we did biodiversity and we looked at, how everything is connected. We used the internet, we did an assembly item and one of the kids dressed up as a spider. She was like the narrator and she told the story. All the kids came out one by one and were joined on a piece of the web, every child had a big card in front of them, they were all animals. (T3)

Each of the teachers could identify their students' learning in terms of increased content knowledge (e.g. spider body parts) and skill development (e.g. observation, drawing and labelling of diagrams, and mapping):

> They didn't realise how many different spiders there are, like [at the start of the unit] they all could just name two spiders, Huntsman and Daddy Long Legs, whereas by the end of it they were able to name six or seven spiders that they could find around the place. (T1)

One of the key aspects to emerge from the interviews was that each teacher was able to articulate the increased capacity of students to act in "social and ethically" responsible ways (Tytler, 2007). They gave numerous examples of students' engagement with the topic and their increased knowledge of and respect for living creatures and their place in nature:

> The before and after activities showed the ones who understood the importance of spiders. At the start you'd have "spiders eat stuff", but by the end, they knew spiders were good because they controlled pests. The other thing was the anatomy of spiders. They went from drawing a spider with a head, body and legs, to drawing cephalothorax, abdomen, and eight-jointed legs …the correct terminology that they used, and also a shift in attitude of what they're doing to spiders. At the start it was "kill it" it by the end it was more like "get someone else to take it outside". (T1)

Ideally, assessment should accommodate learner diversity. In this study, set in a region of high socio-economic disadvantage, each of the teachers mentioned the need to adapt their practices to assist student learning, including the authentic assessment of their students:

… with this class that I was teaching, because there's so many different levels and Negotiated Education Plan kids, and kids that just don't come to school and come once a week or once a month, you really had to negotiate what you were assessing. (T2)
Something that maybe we [teachers] don't do as well as we could, is doing the pre stuff, "What do you know?" first, and then "What do you know after?" because with the spider, looking at those drawings, for example, was a huge shift in what they were able to do. (T3)

Strand 8: Teacher Learning (46 Comments)

The interview data revealed themes that connected closely to Tytler's proposed curriculum framework in terms of teacher learning; for example, the need to make links between tertiary and school science and having school-based pedagogically focused professional learning. Meetings were held at each teacher's school as well as at the University campus:

I think the regular meetings. As much as the school doesn't like you missing your classes, I think having regular meetings, because you can really get off track with your teaching load. But then when you have your meetings and you sort of get motivated again, and then sort of the next couple of days you spend doing Operation Spider stuff, so I definitely think regular meetings … and even if it is after school for an hour, it's still great. (T1)
Having the days at the Uni, being able to work with staff, it was actually quite enjoyable and it was a change from what we're used to doing. I just enjoyed that side of it. Being in a different environment and working with teachers from other schools, that was good. (T2)

The teachers also talked about the impact of role models on their own science teaching practice. A number of their examples related to the influence that pre-service lecturers, the academics specifically involved in the citizen science aspect of this PLP, and even their own primary teachers have had upon them. These comments highlight the importance of educators in shaping people's views about science:

Received great support from you … like in helping us in the developmental stages [of planning]. We sort of were doing it but didn't really know we had to sort of keep it specific otherwise it was just going to blow out too big, so guiding us into what our actual [research] questions were that we were going to try and answer was great. (T1)

One of the teachers was interested in being part of the initial planning of the PLP, so that she could understand the big picture and provide input about her needs right from the start:

It might be useful to be involved in the [initial project] planning stage just to give me more understanding of the planning, because then you can just transfer that into your classroom, so yeah, that would be, I think it would be interesting and possibly useful. (T3)

This was an interesting comment because the first PLP session did in fact address identifying needs. This suggests that the first session might be so overwhelming to new participants that it is important to re-visit initial thoughts early in the programme; it might also mean that more explicit information should be provided prior to teachers coming to the first meeting.

Discussion

While Tytler's (2007) proposed curriculum framework for science was not intended for the purpose of designing teacher professional learning activities, we found it a useful but challenging tool for reviewing our PLP. We were able to identify aspects of our work that addressed the themes and sub-themes identified by Tytler as important in engaging Australian school students in science. We call these the "professional learning programme's strengths". The programme's strengths included Strand 1 (*Conceptual content and context*: Cater for student interest, meaningful contexts, topic of local relevance), Strand 2 (*Pedagogy*: Varied strategies, student agency) and Strand 8 (*Teacher learning*: Teacher PD needs to be school-based).

We were also able to identify sub-themes where we had no evidence of the impact of the PLP. We call this a "scarcity in the data". For example, the interview data provided little evidence that the school-based science experiences empowered students to investigate and reason, which Tytler identified as important to science learning. Strand 4 (*Investigating science*: Investigations), in Strand 5 (*Capabilities relating to science*: Investigating), in Strand 2 (*Pedagogy*: Working scientifically) and in Strand 7 (Assessment). Recognising these gaps has been invaluable to us and will be central to the design of future PLPs.

Further, we were able to identify two areas of strength in our work that we felt had not been fully addressed by Tytler's framework but which we see as important in encouraging student engagement in science. We call these "extensions to the framework". For example, first, and of particular relevance to the context of this study, is the need to acknowledge the cultural capital students bring to the classroom and the diversity of student interests and needs. According to the teachers in this study, few of their students initially regarded science as a core subject that could offer career opportunities. Hence, we were able to specifically address this area of need through whole-class visits to the university whereby students could be exposed to the range of careers that require science understandings. Second, is the importance of connecting students to the natural world and thus, to their well-being. We were specifically able to address this aspect through encouraging and supporting the teachers to take these behaviorally challenging students outside the classroom and by showing them how to scaffold students and teach them to gather data from their school, home and local area.

This study has demonstrated how a PLP delivered through a project such as citizen science can not only motivate teachers who lack the confidence and background to teach science. There was strong evidence that students of these teachers have not only been engaged with learning about spiders in school but also at home, and often with their parents and grandparents. Students' cognitive, procedural and affective learning were evident in teachers' responses. For example, they reported that student outcomes included: the identification of a variety of spider species found in the school yard and in their backyard, the use of Google Maps to identify where trapdoor spiders were located in the school grounds, the development of observational drawing skills to anatomically represent spiders mounted in resin, and the construction of spider models out of recycled/found materials. It was apparent from these teachers that they viewed a topic such as spiders as trans-disciplinary in nature and strongly connected to student's everyday lives, interests and needs.

This case study has also identified two elements of teacher professional learning which needed greater emphasis. First, the need to further focus attention on how to address student-lead inquiry-based investigations in science. Second, to give greater prominence to developing teachers' practices in collecting evidence for assessing the science learning of their students.

Concluding Comments

This case study has reported on a Professional Learning Programme designed to develop teachers' practices in teaching science. It utilised a proposed science curriculum framework to explore the strengths and weakness of the PLP. Using a respectful collaborative approach, volunteer academics and teachers worked together to enhance the teachers' pedagogy, increase their science content knowledge and build their confidence to plan, implement and evaluate interactive units of work that were connected to student's interests and their needs as learners. Regular meetings, the provision of additional planning time and access to a wide range of resources assisted this process. Although originally designed to assist curriculum development in schools, using a curriculum framework such as that proposed by Tytler (2007) can be beneficial for providers of professional learning, who need to address curriculum development and school-based implementation. It would be useful to now develop a model of professional learning which takes the findings of this case study into account and which more fully integrates with such a framework.

Acknowledgements

We would like to acknowledge that the research for this paper was possible due to funding from the Department of Education and Workplace Relations to improve outreach programmes to primary and secondary schools in low socioeconomic areas. The funding provided teacher release which enabled professional learning and classroom action research projects to be undertaken. We would also like acknowledge the commitment of the three teachers involved.

Appendix

TABLE 2

The evaluation framework, adapted from Tytler 2007, p. 64, Table 10

Strand	*Our description*	*Number of Comments*	*Tytler's words (slighty adapted)*
1: Conceptual content and context	Cater for student interests	21	The curriculum needs to seriously cater for student interest
	Meaningful contexts	16	The curriculum needs be set within contexts that will be meaningful to all students.
	Content in meaningful contexts	13	The content of science needs to be set within these contexts
	Key science concepts	2	The content needs to be introduced on a need-to-know basis but structured so that major ideas are covered.

TABLE 2

(continued)

Strand	*Our description*	*Number of Comments*	*Tytler's words (slighty adapted)*
	Appropriate amount of content	3	The amount of content coverage needs to be reduced.
	Contemporary content	1	Content should be chosen to represent contemporary practice,
	Useful content	16	Content useful in students' current and future lives as citizens.
	Topic of local relevance	13	Content should not be restrictive but needs to allow room for initiatives built around local conditions.
		Total: 85	
2: Pedagogy	Varied strategies	18	Teaching strategies in science need to be more varied
	Student agency	12	Teaching strategies with greater agency accorded to students to pursue ideas and have input into discussion
	Using new ideas	0	Ideas should be treated as tools to be used flexibly, rather than simply recalled and recounted,
	Working scientifically	1	A premium put on testing of ideas.
	Communicating science	9	Explicit attention to the literacies of science and the role of representation in learning;
	Reasoning	0	Explicit attention to reasoning in science
	Aesthetics	2	Explicit attention to aesthetics and narrative elements in science learning
	Resources	14	Student have access to adequate learning resources e.g. online, texts, equipment
		Total: 56	
3: The way science works	Science in society	7	Attention paid to the workings of science in contemporary society, including sociological aspects.
	Understanding the nature and importance of science	0	Attention paid to the workings of science in contemporary society, including epistemic aspects.

TABLE 2

(continued)

Strand	*Our description*	*Number of Comments*	*Tytler's words (slighty adapted)*
	Science in society	2	The curriculum strongly represent the way science interacts with society
	Science and technology	0	The curriculum should strongly represent the way science interacts with technology
	Risk, values and ethics	4	The curriculum should strongly represent the way science includes concepts such as risk and questions of value and ethics.
	Nature of evidence	3	Strongly represent the way knowledge is established in science, the nature of scientific evidence
	Investigations	4	It should strongly represent the processes of science investigation, via rich representations.
	Nature of science	2	It should strongly represent the nature of scientific evidence.
		Total: 22	
4: Investigative science	Investigative principles	0	Science investigations need to be more varied, with explicit attention paid to investigative principles.
	Investigating methods	4	Investigative design should encompass a wide range of methods and principles of evidence including sampling, modelling, field-based methods, and the use of evidence in socio-scientific issues.
	Student questions	3	Investigations should frequently flow from students' own questions.
	Constructing understandings	0	Investigations should exemplify the way that ideas and evidence interact in science.
		Total: 7	
5: Capabilities relating to science	Nature of science	1	Widen the capabilities currently associated with school science to include understandings of the nature of science and the

TABLE 2

(continued)

Strand	*Our description*	*Number of Comments*	*Tytler's words (slighty adapted)*
			way it works both in a research and a societal sense.
	Investigating	1	Widen the capabilities currently associated with school science to include the capacity to investigate and reason.
	Engagement	8	Widen the capabilities currently associated with school science to include dispositional capabilities such as interest and curiosity andappreciation of the workings and methods of science.
	Generic capabilities	4	Widen the capabilities currently associated with school science to include more broadly generic capabilities such as thinking analytically, communicating and working in teams, and creativity and imagination.
	Student attitudes	7	Explicit attention to student attitudes and their development
		Total: 21	
6: The setting of school science	Transdisciplinary	9	School science should be linked more often and more closely with local and wider communities, and science should be studied in community settings that represent contemporary science practices and concerns.
	Community science	0	Ways need to be found to embed school–community initiatives into the curriculum in sustainable ways.
		Total: 9	
7: Assessment analysis	Investigations	0	Assessment of investigative capabilities
	Science in society	8	Assessment of the capacity to explore science in social and ethical contexts.
	Thinking skills	0	Assessment of reasoning and imagination.
	Nature of science	0	Assessment of the nature of science.

TABLE 2

(continued)

Strand	*Our description*	*Number of Comments*	*Tytler's words (slighty adapted)*
	Authentic assessment	3	authentic, learning-based assessment practices
		Total: 11	
8: Teacher learning	Tertiary science	8	There is a need for tertiary science to align with the re-imagined school science practices.
	Teacher education	38	Teacher professional learning needs to be school based, and should focus substantially on pedagogy.
		Total: 46	

References

Australian Academy of Science (2010) *Primary Connections*, Canberra, A.C.T. Australian Capital Territory:Author

Australian Curriculum and Assessment Reporting Authority (ACARA) (2013) Retrieved 8 August 2013 from http://www.australiancurriculum.edu.au/

Berkowitz, A. R. (1997). A simple framework for considering the benefits of SSPs. In K. C. Cohen (Ed.), *National Conference on Student and Scientist Partnerships* (pp. 38–41). Cambridge, MA: TERC and Concord Consortium.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. & Wilderman, C.C. (2009). *Public participation in scientific research: Defining the field and assessing its potential for informal science education*. Washington DC: Center for Advancement of Informal Science Education (CAISE).

Bowers, C. A. (2001). *Education for eco-justice and community*. Athens, GA: The University of Georgia.

Bowers, C. A. (2006). *Revitalizing the commons: Culture and educational sites of resistance and affirmation*. Oxford, UK: Lexington.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practical action*. Portsmouth, NH: Heineman.

Bybee, R.W. (2006). *Enhancing science teaching and student learning: A BSCS perspective*. Retrieved 28 September 2006 from http://www.acer.edu.au/workshops/conferences.html

Clark, I. & Zeegers, Y. P. (2012). Education for sustainable development: Improving curriculum design in higher education. In C. Daniels & P. Roetman (Eds.), *Creating sustainable communities in a changing world* (pp. 225–232). Adelaide: Crawford House Publishing, Adelaide, Australia

Cobern, W. W. (1993). Contextual constructivism: The impact of culture on the learning and teaching of science. In K. G. Tobin (Ed.), *The practice of constructivism in science education* (pp. 51–69). Washington, DC: American Association for the Advancement of Science.

Cobern, W. W. (1994). World view, culture, and science education. *Science Education International, 5*(4), 5–8.

Coertjens, L., Boeve-de Pauw, J., Maeyer, D. & Petegem, V. (2010). Do schools make a difference in their students' environmental attitudes and awareness? *Evidence from Pisa 2006 International Journal of Science and Mathematics Education, 8*(3), 497–522.

Cornish, L. & Jenkins, K. (2012). Encouraging teacher development through embedding reflective practice in assessment. *Asia Pacific Journal of Teacher Education, 40*(2), 159–170.

Department of Education and Children's Services (2010). *South Australian teaching for effective learning (TEFL): South Australian Teaching for Effective Learning Framework Guide: A resource for developing quality teaching and learning in South Australia*. Retrieved 28 August 2013 from http://www.learningtolearn.sa.edu.au/tfel/files/links/SA_TfEL_Framework_horizont.pdf

Dickinson, J. & Bonney, R. (Eds.). (2012). *Citizen science: Public participation in environmental research*. London: Comstock, London, United Kingdom.

Faire, J. & Cosgrove, M. (1993). *Teaching primary science*. Hamilton, New Zealand: Waikato Education Centre.

Fensham, P. J. (2003). What do the "All" need in science education? In D. Fisher & T. Marsh (Eds.), *Third Conference on Science, Mathematics and Technology Education* (pp. 1–20). Rhodes University, South Africa: Key Centre for School Science and Mathematics, Curtin University of Technology.

Hayes, D., Mills, M., Christie, P. & Lingard, B. (2006). *Teachers and schooling making a difference: Productive pedagogies, assessment and performance*. Crows Nest, Australia: Allen & Unwin.

Hodson, D. (1993). In search of a rationale for multicultural science education. *Science Education, 77*(6), 685–711.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645–670.

Kim, M., Yoon, H., Ji, Y. & Song, J. (2012). The dynamics of learning science in everyday contexts: A case study of everyday science class in Korea. *International Journal of Science and Mathematics Education, 10*(1), 71–97.

Kinna, D. & Paige, K. (2010). Connecting year 9 mathematics to the community: An action research project. In B. Prosser, B. Lucas & A. Reid (Eds.), *Connecting lives and learning: Renewing pedagogy in the Middle Years* (pp. 60–72). Adelaide: Wakefield Press, Adelaide, Australia.

Mamlok-Naaman, R. & Eilks, I. (2012). Different types of action research to promote chemistry teachers' professional development—A joined theoretical reflection on two cases from. *Israel and Germany International Journal of Science and Mathematics Education, 10*(3), 581–610.

Matthews, M. (1992). History, philosophy and science teaching: The present rapprochement. *Science & Education, 1*(1), 11–47.

Matthews, M. (Ed.). (2009). *Science, worldviews and education*. Springer. Science & Business Media. http://link.springer.com/book/10.1007/978-90-481-2779-5

Moll, L., Amanti, C., Neff, D. & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes to classrooms. *Theory Into Practice, 31*(2), 132–141.

Moss, D. M., Abrams, E. D. & Kull, J. A. (1998). Can we be scientists too? Secondary students' perceptions of scientific research from a project-based classroom. *Journal of Science Education and Technology, 7*, 149–161.

Murray, J., Cawthorne, G., Dey, C. & Angrew, C. (Eds.). (2012). *Enough for all forever: A handbook for learning about sustainability*. Champagne, Illinois: Common Ground, Illinois, IL.

Osborne, J. (2006). *Towards a science education for all: The role of ideas, evidence and argument*. Paper presented at the ACER Research Conference: Boosting Science Learning- What will it take? Canberra, Australia. http://www.acer.edu.au/workshops/conferences.html

Paige, K., Lawes, H., Matejcic, P., Taylor, C., Stewart, V., Lloyd, D. & Daniels, C. et al. (2010). 'It felt like real science!': How Operation Magpie enriched my classroom. *Teaching Science, 56*(4), 25–33.

Paige, K. & Lloyd, D. (2011). Educating for sustainability: A vehicle for engaging primary/middle education students in science. In P. E. J. Roetman & C. B. Daniels (Eds.), *Creating sustainable communities in a changing world* (pp. 239–247). Adelaide: Barbara Hardy Institute, University of South Australia, Adelaide, Australia.

Paige, K. & Lloyd, D. (2012). Pedagogical practices and science learning with a focus on sustainability for pre-service primary and middle years educators: Directions and challenges. In M. Daniel & S. W. Hwang (Eds.), *Moving forward: Issues and challenges in science education research* (pp. 191–208). Singapore: Springer.

Paige, K., Lloyd, D., Zeegers, Y., Roetman, P., Daniels, C., Hoekman, B., Linnell, L., George, L. & Szilassy, D. (2012). Connecting teachers and students to the natural world through *Operation Spider*: An Aspirations Citizen Science Project. *Teaching Science, 58*(1), 13–21.

Pedretti, E. (1997). Septic tank crisis: A case study of science, technology and society in an elementary school. *International Journal of Science Education, 19*(10), 1211–1230.

Prosser, B., Reid, A. & Lucas, B. (Eds.). (2010). *Connecting lives and learning: Renewing pedagogy in the middle years*. Adelaide: Wakefield Press, Adelaide, Australia.

Rennie, L. (2006). *The community's contribution to science learning: Making it count*. Retrieved 23 September 2006 from http://research.acer.edu.au/cgi/viewcontent.cgi?article=1006&context=research_conference_2006

Riddle, E. M. (1999). *Lev Vygotsky's social development theory*. Retrieved 3 March 2007 from http://tonymcarthur.edublogs.org/files/2007/03/vygotsky1.htm

Ritchie, J. & Spencer, L. (1994). Qualitative data analysis for applied policy research. In A. Bryman & R. G. Burgess (Eds.), *Analyzing qualitative data* (pp. 173–194). London: Routledge, United Kingdom.

Roetman, P. E. J. (2013). *The 'citizen' in citizen science: The research, education and engagement of a program based on local wildlife species in South Australia*. University of South Australia, Unpublished doctoral thesis, Adelaide.

Roetman, P. E. J. & Daniels, C. B. (2011). The benefits of citizen science in research, education and community engagement. In P. E. J. Roetman & C. B. Daniels (Eds.), *Creating sustainable communities in a changing world* (pp. 249–260). Adelaide: Crawford House Publishing, Adelaide, Australia.

Rogers, M., Abell, S., Lannin, J., Wang, C., Musikul, K., Barker, D. & Dingman, S. (2007). Effective Professional Development in Science and Mathematics Education: Teachers' and Facilitators' Views. *International Journal of Science and Mathematics Education, 5*(3), 507–532.

Roth, W.-M. & Désautels, J. (Eds.). (2002). *Science education as/for sociopolitical action*. New York: Peter Lang, New York, NY.

Solomon, J. & Aikenhead, G. (Eds.). (1994). *STS education: International perspectives on reform*. New York: Teachers College Press, New York, NY.

Tinker, R. F. (1997). Student scientist partnerships: Shrewd maneuvers. *Journal of Science Education and Technology, 6*, 111–117.

Trautmann, N. M., Shirk, J. L., Fee, J. & Krasny, M. E. (2012). Who poses the questions? Using citizen science to help K-12 teachers meet the mandate for inquiry. In J. L. Dickinson & R. Bonney (Eds.), *Citizen science: Public participation in environmental research* (pp. 179–190). Ithaca, NY: Comstock.

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Camberwell, Victoria: ACER Press.

Tytler, R., Symington, D. & Smith, C. (2011). A curriculum innovation framework for science, technology and mathematics education. *Research in Science Education, 41*(1), 19–38.

Waldrip, B., Prain, V. & Carolan, J. (2010). Using multimodal representations to improve learning in junior secondary science. *Research in Science Education, 40*(1), 65–80.

Wilson, J. & Lloyd, D. (2010). Connecting lives and learning: Super size me with science. In B. Prosser, A. Reid & B. Lucas (Eds.), *Connecting lives and learning: Action research in the Middle Years of schooling* (pp. 73–93). Adelaide: Wakefield Press, Adelaide, Australia.

Zeegers, Y. & McKinnon, H. (2012). 'Does a spider have fur'? Blending primary science and English language learning for ESL students. *Teaching Science, 58*(3), 7–13.

Zeegers, Y., Paige, K., Lloyd, D. & Roetman, P. (2012). Operation Magpie: Inspiring primary school teachers through science-focused professional learning experiences. *Australian Journal of Environmental Education, 28*, 27–41.

Zoellick, B., Nelson, S. J. & Schauffler, M. (2012). Participatory science and education: Bringing both views into focus. *Frontiers in Ecology and the Environment, 10*(6), 310–313.

Kathryn Paige, Yvonne Zeegers and David Lloyd
School of Education
University of South Australia
Mawson Lakes Campus, GPO Box 2471, Adelaide 5001, Australia
E-mail: kathy.paige@unisa.edu.au

David Lloyd and Philip Roetman
Barbara Hardy Institute
University of South Australia
Adelaide, Australia