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Building Future Directions for Teacher Learning in Science Education

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Abstract In 2013, as part of a process to renew an overall sector vision for science education, Catholic Education Melbourne (CEM) undertook a review of its existing teacher in-service professional development programs in science. This review led to some data analysis being conducted in relation to two of these programs where participant teachers were positioned as active learners undertaking critical reflection in relation to their science teaching practice. The conditions in these programs encouraged teachers to notice critical aspects of their teaching practice. The analysis illustrates that as teachers worked in this way, their understandings about effective science pedagogy began to shift, in particular, teachers recognised how their thinking not only influenced their professional practice but also ultimately shaped the quality of their students' learning. The data from these programs delivers compelling evidence of the learning experience from a teacher perspective. This article explores the impact of this experience on teacher thinking about the relationship between pedagogical choices and quality learning in science. The findings highlight that purposeful, teacher-centred in-service professional learning can significantly contribute to enabling teachers to think differently about science teaching and learning and ultimately become confident pedagogical leaders in science. The future of quality school-based science education therefore relies on a new vision for teacher professional learning, where practice explicitly recognises, values and attends to teachers as professionals and supports them to articulate and share the professional knowledge they have about effective science teaching practice.

Keywords Teacher professional learning · Science education · Effective pedagogy · Teacher thinking · Student learning · Pedagogical leadership · Teacher professional knowledge · Cases as data · Teaching science

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Introduction

There are challenges associated with the provision of in-service teacher education programs, particularly, those that aim to build teacher capacity to affect and support change in school-based science education. Foremost is the complex nature of teacher thinking and the interrelatedness of various dimensions of teacher practice, e.g. individual teacher thinking about curriculum content and pedagogy, the diverse contextual realities of teaching and the greater context of teaching itself (Anderson et al. 2000; Ball 1997; Cobb and Bowers 1999; Mockler 2011; Putnam and Borko 1997). To address these concerns effectively requires teacher in-service education programs to find ways to strategically attend to the diverse knowledge of practice which teachers themselves develop and use everyday in their teaching: a knowledge shaped by experience and context, defining their professional expertise. While much of the contemporary literature associated with teacher professional learning continues to evidence 'successful' program practice as that which produces teaching routines compliant with program intention, then teaching remains defined as a technical activity and the importance of teacher as a discerning and knowledgeable professional remains overlooked. Understanding the conditions that enable teachers to engage in meaningful learning depends upon a willingness of research to investigate opportunities that assist teachers to identify and reconsider aspects of professional practice that are personally significant or problematic. The research discussed in this article is therefore important because it attempts to explore data to understand more about how reimagined approaches to in-service teacher education impact the way teachers think about and enact their science teaching practice. Different types of data were examined from two teacher in-service programs in science education. In both programs, teachers and their professional thinking were deliberately positioned at the centre of the learning experience and teachers were supported to critically examine their science teaching practice to find personally meaningful ways to think and work differently. The analysis pays attention not only to the learning that emerged but also the conditions that enabled learning. The data suggests that because these programs created opportunities for teachers to experience science in new ways, they began to recognize their professional expertise as science educators and their thinking shifted. This was evident by increased confidence in science teaching together with a capacity of teachers to articulate new ways of thinking about pedagogy, in particular, ways of enhancing student learning.

The findings suggest that meaningful teacher learning requires teacher in-service programs to find ways to explicitly attend to the inherent complexity of teacher thinking and the diversity of teachers' learning needs (Hammerness et al. 2005) so that teachers may reconsider the purpose and intent of their science teaching and their students' learning.

Tensions Between Teacher Development and Teacher Learning

> Specifically, staff development programs are designed to "alter the professional practices, beliefs, and understanding of school persons toward an articulated end" (Griffin 1983, p. 2). In most cases, that end is the improvement of student learning.
> (T.R Guskey 1995, p. 5)

Guskey's quote highlights a prevailing accepted assumption that underlies the intent of teacher in-service education: to engineer improvement in schools and student learning by altering teacher thinking and practice. While the ultimate goal of in-service education programs may be to improve student learning, this paper questions the habitual acceptance of approaches to in-service teacher education that assume those outside of teaching are best placed to determine the type of changes teachers need to undertake in order achieve such outcomes. To illustrate this thinking further, it may be useful to construct a theoretical dichotomy to characterise two distinctly different philosophical positions which presently frame teacher in-service education: professional development (PD) and professional learning (PL). In PD, a traditional approach to in-service education, the determinants of program design, content and learning outcomes largely reside with those external to the practice of school-based teaching. There is a tendency for such programs to focus on what teachers do rather than what they think or know about teaching, thus positioning teachers as 'technicians' attending to them as objects 'needing to be improved or developed' rather than subjects of change (Ovens 2006). Such approaches are ultimately problematic for teacher learning because they produce learning conditions that tend to marginalize teachers from decision-making and position them as anonymous participants within a mechanical process of professional development. PL programs theoretically recognize the central role that teachers play in the learning process: shaping the experience of learning and ultimately determining the learning outcomes and the impact on personal practice. PL programs adopt approaches that recognise teacher learning is not a mechanical process (Day 1999), and teachers need to be positioned as active learners and key decision makers about what matters in terms of personal professional learning. PL recognises teachers as 'intellectuals', and their professional expertise is positioned at the centre of the learning experience.

This dichotomy, while theoretical in nature and not always obvious in practice, is useful to highlight a number of assumptions and practices that appear to drive prevailing approaches to teacher in-service education. The programs cited in this research are aligned with the theoretical intent of PL and acknowledge that teachers, as professionals, are committed to personal learning that further develops professional expertise. Therefore, meaningful teacher learning relies on the individual teacher seeing a need to think and work differently (Fullan 1993; Guskey 2009; Hargreaves and Shirley 2012), and this is less likely to happen when teachers are disenfranchised from discussions concerning what they 'need' to learn, how this learning should take place and what outcomes are valued.

Identifying Effective Conditions for Teacher Learning: Understanding Teacher Professional Knowledge

What matters to teachers as they participate in professional learning? Research suggests that teachers readily recognize the weakness of learning experiences, which in their eyes are fragmented, shallow, frustrated and disconnected from their real teaching situation (Hawley and Valli 2000). Alternatively, they appear to find meaning in professional learning experiences that involve them in decisions about the direction and process of their own learning and that allow them to experiment with new teaching procedures (Smith 2015). These types of experiences appear to encourage and support teachers to construct a knowledge base directly related to the context of their own teaching and learning practice (Borko 2004; Plummer 2005; Smith 2015). Professional learning therefore must enable teachers to explore the professional knowledge they develop and articulate how this knowledge shapes and informs the many decisions they make in their science teaching.

Establishing a clear understanding of the nature of teacher professional knowledge is surrounded by debate about what constitutes knowledge of practice and how it might best be described (Berry et al. 2009). Fenstermacher (1994) highlighted the distinction between the formal knowledge of teaching (the knowledge created by educational researchers) and the practical knowledge of teaching (the knowledge created by teachers through their experiences of classroom teaching) (Berry et al. 2009). According to Loughran (2010), 'traditionally academic knowledge of teaching has had little impact on practice' (p. 41) as this knowledge provides information that is not always compelling to teachers and the dilemmas they face in the everyday work of their teaching. Loughran cites a number of reasons for this yet makes the point that it would be incorrect to assume that teacher work is atheoretical (Loughran 2010). Teachers do use and adapt academic knowledge that they see which makes a difference to their practice and which helps them to understand or explain their experiences; they are expert at using and adapting this knowledge in meaningful and practical ways.

Teacher knowledge of practice appears to be largely tacit (Korthagen 2001; Loughran 2010) deeply embedded in each teacher's everyday practice. Therefore, observations of teaching actions alone, as an indicator of such knowledge, become problematic. Opfer and Pedder (2011) describe an 'epistemological fallacy' of current research around teacher professional learning which takes empirical relationships between the technical aspects of teaching and some measures of teacher change to be teacher learning. They argue that such research effectively reduces the 'real' to empirical experience (Opfer and Pedder 2011). Such observations may provide very little information about why teachers approach teaching in particular ways, how they construct their knowledge of teaching procedures, how they apply such knowledge to enhance students' learning, and how they interpret teaching situations and recognize and respond to student learning difficulties. These are just some of the features of teachers' work implicit within their practice. For this reason, these aspects of practice and professional knowledge are not only difficult to observe but they are not always central to the ways in which teachers talk about the complex work of teaching and learning (Berry et al. 2009). Accessing such information requires attempts to make the implicit explicit, in real terms, this relies on teachers themselves sharing their thinking, describing their learning from their own perspective. If teacher professional knowledge of practice matters, then it must be the teachers themselves who make this knowledge explicit (Loughran and Berry 2011). Professional learning programs must find ways to provide learning conditions which effectively enable teachers to recognise, value and articulate the professional knowledge they hold and use everyday. Only then can teachers feel empowered to address problematic aspects of their practice in ways that are personally meaningful and contextually relevant.

Research Context and Participants

Catholic Education Melbourne (CEM) is a large educational sector responsible for the development and support of schools operating within the third-largest Catholic diocese in the world. In 2014, this region comprised approximately 149,400 students enrolled in 329 Catholic schools supported by more than 16,700 teaching and non-teaching staff. The schools within this boundary are characterised by a diversity of needs and social and academic contexts. The CEM works to strategically focus operational vision to ensure that sector practice in education promotes and supports efforts of quality learning and purposeful teaching.

In 2013, the sector undertook a review of a range of in-service teacher education programs available to science teachers at all levels of schooling. Data from this review frames this article and refers to information collected in relation to two key PL initiatives: the *Science Teaching and Learning* (STaL) program and the *Contemporary Approaches to Primary Science* (CAPS) program. The review was to determine the effectiveness of these programs in enabling science teachers to enhance their teaching and school-based science education and provided a great opportunity to research the effectiveness of these programs in terms of teacher learning. Data was collected from each program revealing that both have been effective in shifting teachers' thinking about science teaching and learning. The STaL data also captured how teacher thinking about teaching practice began to change in ways, which enhanced science teaching. In the following sections, each program will be discussed in turn providing information about program design intentions, data sets and method of analysis and findings about the impact of the program experience in terms of teacher thinking and, in the case of the STaL data, teaching practice.

Program 1: STaL

STaL was a collaborative project between Monash University and CEM involving a 5-day intensive, residential program, following a configuration of 2×2 day workshops and one writing day. These days were spread over a school year from February to December. Key personnel from the *Centre for Science, Maths and Technology Education*, Faculty of Education at Monash University, facilitated the program. Associated costs including all accommodation, meals and a percentage of teacher release costs were covered by the CEM.

Participants From 2006–2012, seven programs were conducted involving a total of 226 science teachers. Each year, the program cohort of approximately 30 teachers comprised a mix of both primary and secondary teachers. All science teacher participants were volunteers with a premium placed on attracting (wherever possible) pairs of teachers who worked together in the same school, although some individual teachers also enrolled in the program.

Program Aim and Conditions for Learning

The program aimed to build participant capacity to be reflective practitioners (Schön 1983). Teachers were placed in the position of learners of science and were supported to reconsider their existing approaches to science teaching in an attempt to reconceptualise their practice through a serious focus on student learning. Further details about the program's intentions for teacher learning are discussed at length in Berry et al. (2009). In addition to the five workshop days, each teacher was supported with individual school visits where a facilitator, assigned to the role of 'Critical Friend', visited all schools approximately three times across the program year. These school-based discussions aimed to promote reflective thinking and support teachers to identify critical moments in their teaching when they were confronted with dilemmas or challenges. Teachers were encouraged to talk about these times and identify and trial alternative teaching strategies in school-based science education. The final day of the program was a writing day when teachers worked to produce a case capturing their professional thinking and learning about the critical moments within their teaching practice.

Data

The final day of STaL was a case-writing day where each participant completed a written case (Barnett and Tyson 1999; Shulman 1992) which captured their professional learning and thinking as a result of their program experience.

The activity of case writing provided participants with an opportunity to reflect on and articulate aspects of practice that were specific to their own needs and contexts. This process enabled participants to articulate insights they had gained about their practice and embed this thinking within the alternative perspectives and approaches they had trialled to change science teaching and learning within their classrooms and schools. Mason's (2002) concept of the inner witness became a useful construct for data collection methods, i.e. finding ways of capturing teacher awareness of the internal conversations they experienced which enabled them to determine why some learning experiences mattered and other ideas and experiences do not (Clegg 2005). Cases were regarded as a useful way to do this as they provided an insight into these internal conversations and often evidenced that teachers had shifted knowledge of practice from tacit to explicit. Over the life of the program, all science teacher participants produced a written case (N=226). These cases formed a large and rich data set which was analysed as part of the overall review and categorized to develop an understanding of the range of issues prominent among science teachers, prevalence of these issues across various cohorts of participants and changes in teacher thinking about these issues as a result of experience in STaL.

Analysis: Constructing Categories of Description

Extensive analysis of the 226 cases was undertaken to determine the impact of the STaL program on teacher thinking about science teaching practice. As all participants were employees within the system, ethics clearance was gained as part of an overall collaborative research with Monash University. Case writing data has formed the basis of a number of ensuing research publications including *Capturing and enhancing science teachers' professional knowledge* (Berry et al. 2009), *Making a Case for Improving Practice: What Can Be Learned About High Quality Science Teaching from Teacher-Produced Cases?* (Loughran and Berry 2011) and *Facilitating Change in Science Teachers' Perceptions About Learning and Teaching* (Loughran and Smith 2015).

The analysis undertaken for the research cited in this article explored descriptive nature of the language used in cases writing, and this information was sorted and categorized according to similarity of ideas and issues while also discerning the differences between such responses. The purpose of the process of analysis was not to correctly and absolutely assign labels to every aspect of each case but rather to identify the different ways teachers described and characterised particular challenges or considerations in their science teaching.

The analysis was undertaken in three stages.

Stage 1: Individual case analysis

The first stage of the data analysis involved close reading of each case to identify:

- Any specific issue or issues relating to science teaching or learning captured in the writing;
- Changes in teacher thinking around these issues.

Stage 2: Identification of emerging recurring issues across cases

Noticing the nature of the language teachers' used as they described issues enabled patterns of descriptions to be marked across the data set. A constant comparative method was applied to identify the similarities, differences and prevalence of these concerns across the cases. As a result of stage 2 analysis, 20 broad issues were identified.

Stage 3: Constructing overall categories of description

In an attempt to manage and understand the interrelatedness of these issues, the third stage of analysis re-examined the 20 issues looking for connections, which could be used to identify major themes as a basis for sorting and categorising this information. As a result of this stage of analysis, three broad themes of teacher learning were identified: the nature of science teaching, pedagogy and assessment. These three themes formed the basis of three major categories, each characterised by a collection of interconnected issues. In essence, these categories captured what was for many teachers, the foci of their professional learning experience.

This article takes the findings associated with one of these categories, 'pedagogy', and uses this as an example of how the teacher thinking and practice was influenced by their participation in this program experience. Figure 1 *Teacher thinking about pedagogy—a category of description* outlines the corresponding issues related to this category

Teacher Thinking About Pedagogy

Definition of This Category of Description

The category 'pedagogy' did not simply refer to science teaching, it was expressed in various cases as a complex mix of the interplay between teachers' perceptions about the nature of science teaching, student learning and, in particular, the interdependency and interactive nature of these areas. This complexity defined this category and in so doing conveyed the powerful nature of the professional learning teachers experienced as a result of this professional learning program.

Changes in Teacher Thinking

Generally, cases in this category conveyed the tensions teachers experienced as they began to value and attend to an alternative purpose and vision for their science teaching and their students' learning. The cases in this category explore three big ideas:

- *Reframing learning in science*: exploring the issues experienced by teachers themselves and their students as they attempted to reframe the learning experience, in particular, the roles of the teacher and the student in science education.
- *Student engagement*: describing the types of conditions needed to engage students intellectually, emotionally and behaviourally in science learning.
- *Teaching for understanding*: exploring the work of science teachers as they attempted to personalise student learning.

Figure 2 provides a visual summary of these groupings and the shift in teacher learning, which was evident in these cases. The information is represented as a continuum of teacher thinking, representing and projecting the type of teacher learning that emerged from the data.

Fig. 1 Teacher thinking about pedagogy—a category of description

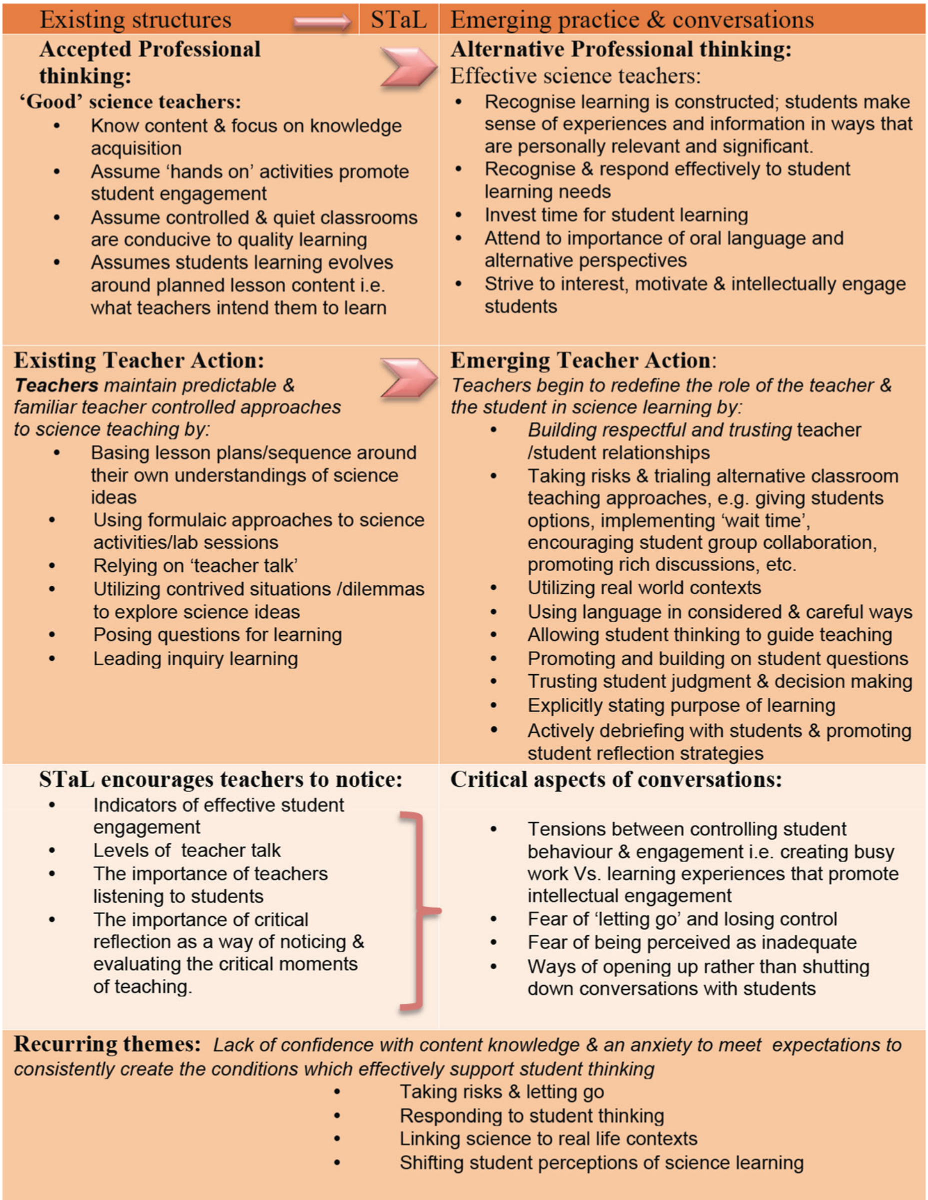

Fig. 2 Pedagogy: a continuum of teacher learning as captured in teacher cases

The data indicated that prior to participating in the STaL program, many teachers described predictable and familiar approaches to science teaching where planning sequences reflected their own rather than their students' understandings of science ideas; science teaching involved lots of teacher talk, more than in other curriculum areas; and science ideas were exemplified in experiments. The data evidenced that as a result of their learning experiences in the STaL program, teachers began to question why they were teaching science in ways they always had, and many teachers conveyed a realization that the teaching behaviours which made them feel in control and confident as a 'good' science teachers, in reality, continually nurtured and reinforced passive student learning behaviours.

> I have learnt a lot about myself as a teacher since participating in STaL. The approach I used as a first year teacher to help ease me into teaching science had stuck with me for the past four years. I didn't realise how confident I had become with the content myself and I didn't really see that I no longer needed to be as reliant on PowerPoint to be in control.
> I found creating ways for students to be independent learners changed my teaching and their learning… I have consciously started to delay judgement and to refrain from simply praising students publicly. As a consequence, they appear much more confident to write what they think and to make contributions to discussions in ways that are new for me and much more meaningful for them (Laba 2012, p. 4.).

Growing from such observations was a desire by teachers to change student behaviour, and this ultimately meant changing classroom conditions. Evidence indicated that teachers engaged in thinking about the need to build respect and trust between themselves and their students. They openly discussed taking risks and trialling alternative classroom teaching approaches involving increased opportunities for student decision-making, linking science to real world events, attending to student curiosity and interest and promoting reflection in learning.

The following case extract illustrates teacher thinking about these types of changes and the challenges such changes presented for both the teacher and the student.

> I looked at the teaching in my Science classes. One of the most challenging and enlightening realizations that I learnt through the Science Teaching and Learning Teacher Research project was just how powerful the relationship between the teacher and their own class of students is. I realized that I needed to know my students much better if I was to teach them well….
> I also began to recognize the importance of helping students to make a real connection with their own world. I also wondered whether that was really possible to achieve. I have started to do this is by asking students questions about what they have previously covered in science and other subjects and how that connects with their everyday life. …
> It has been hard going. There is so much preparation necessary because of the various changes that have to be done: rearranging the classes; giving different explanations; spending the entire class wandering around and dealing with more questions than in the past; and, dealing with students who are stuck and just want to be told what to do….
> I can honestly say that now I feel more confident to start to offer a range of learning approaches, to talk with each student to say for example:
> "Do you like this method John?"
> "What have you learnt today?"
> "What can we do together to improve learning?"
> I am enjoying my teaching more and now I feel as though I can see how my students are learning. It's hard work, but it's worth it (Butler 2007, pp. 106–107).

The data analysis also highlighted the interconnection between teacher action and student learning behaviours. Of particular interest was the 'flow on' effect that appeared to emerge for students' perceptions of science and their perceived role as learners in school science. As teachers elected to change their teaching, students found themselves in unfamiliar science classes. No longer were they encouraged to sit passively and listen; the teacher was not telling them what they needed to know. Teachers were more accepting of student thinking and encouraged students to take part in open discussions; in response, students were expected to take risks and share a variety of ideas, play an active part in decision making by exploring how ideas linked together, demonstrate their understandings and articulate how they were thinking and learning. The following extract demonstrates the challenges such changes posed for both teachers and students and also how students at times actively resisted teacher attempts to personalize and contextualize science teaching and learning.

> "Why haven't you started, girls?" I asked.
> "We don't know what to do," Sally replied.
> "What questions are you investigating?" I inquired.
> "Does looking at an eclipse really send you blind and what effect would it have on eclipses if the moon were a different distance from the Earth?" she answered.
> "Well how do you think you could find that out?" I asked trying my best to push them forward in a positive way.
> "Can't you just tell us the answer?" Michelle retorted.
> "Are you going to mark us on this?" Sally added.
> I must admit that at this stage I was feeling rather frustrated. I was trying to create this wonderful learning experience and all they were interested in was how I was going to mark them……….
> It is perhaps important to accept as a teacher that a single activity is unlikely to result in wholesale change in the mind set and attitudes of my students. Such changes of culture are going to take a long time and may be made more difficult by what is happening in other classes. Helping students learn for understanding is hard work (Bliss 2007, pp. 64–66).

Implications of Findings for Future Directions

The analysis of STaL data is important because it provides an insight into the relationship between conditions for learning and the experience of learning itself. This program encouraged teachers to pay attention to their own teaching and use this as a context for their professional learning. In these conditions, teachers began to consider the relationship between teaching and learning in ways that were personally meaningful and contextually relevant. This data analysis revealed that many teachers as a direct result of participation in a program that placed them at the centre of the learning experience:

- Demonstrated an increased awareness of the importance of planning and teaching to interest, motivate and intellectually engage students,
- Worked to enable students to make sense of experiences and information in ways that were personally meaningful,
- Were more effective in recognising and attending to student learning needs,
- Demonstrated an increased willingness to slow down and invest time for student learning, and
- Attended to the importance of oral language and alternative perspectives in their practice.

The changes evidenced in the data were not standardized or necessarily a common experience for all teachers. Yet, one of the most overwhelming findings which emerged was that while teachers worked in a program where they felt supported to value their knowledge of teaching, they were willing to interrupt their accepted teaching routines to find ways of positioning new and personally valued professional knowledge within their practice. This ultimately changed their science teaching and their students' experience of learning science. As a result, teachers began to rethink their science teaching and notice student learning in new ways. These teachers, while working in professional learning experiences that placed their teaching as the focus of the learning experience, demonstrated a capacity to critically engage with new thinking in ways that influenced their thinking about quality professional practice.

Program 2: CAPS

Generally, it is an expectation across education systems within the state of Victoria that all primary classroom teachers, as generalist teachers, will teach science as part of their regular teaching duties. Rarely within the Catholic sector are primary teachers supported with school-based specialist science teaching staff. CAPS, a program facilitated by CEM science education staff, is designed to specifically support primary science teaching, in particular, the many challenges teachers face in relation to both feelings of low personal adequacy with science and also finding ways to position science so that science learning connects to other areas of the curriculum. Since its inception in 2011, the program has involved an intensive 5-day residential in-service professional learning program following a configuration of 2×2 days+1 day. These days are spread across the school year, i.e. from February to December. The program challenges accepted subject-based approaches to primary science by examining cross curriculum and whole school approaches to planning and teaching. The program provides opportunity for colleagues to work together to discuss values and understandings of science and ideas around quality science learning. Teachers participate in a range of learning experiences including museum visits, working with indigenous elders and school visits. Following all experiences, colleagues are provided with time to discuss developing understandings and consider how such thinking might be positioned within their teaching context. Each team undertakes an action research project to enhance science teaching and learning within their school.

It is expected that each participating school will send a team of at least three teachers to ensure that a critical mass of school staff is involved and therefore able to continue discussions back at school level. The data analysed in this article is taken from the cohort of 2013, when 55 teachers attended the program.

Program Aim and Conditions for Learning

The CAPS program is designed to address concerns that may be specific to the teaching of primary school science. The program promotes pedagogical approaches that essentially value building a 'connectedness' between students and their world, and program sessions explore the notion of scientific literacy as a pedagogical means to engage students with science in the twenty-first century. Sessions also encourage teachers to explore a model of curriculum planning which embeds science skills and knowledge across curriculum areas, i.e. discipline and inter-disciplinary areas. Essentially, the program assists teachers to explore science as part of a holistic approach to teaching, developing the whole person, nurturing in each student a noticing of life and natural phenomena and creating opportunities for students to construct meaning. Science learning is essentially about curiosity, willingness to question and an intrinsic need to seek understanding (Smith 2011). Critical thinking and informed action are seen as ways of encouraging meaningful and purposeful learning, and teachers are encouraged to use their existing pedagogical strengths to enhance these learning outcomes.

Data and Analysis

On the first and also the final day of the CAPS program, participants are asked to complete an anonymous self evaluation form (SEF). The purpose of the SEF is to provide a quick snap shot of the impact of the program by providing an opportunity for participant teachers to self-reflect on their personal learning. The form was used for the first time in 2013 and was organized into four sections requiring teacher participants to explore their own thinking about the value and relevance of the program's learning opportunities in terms of the impact on personal knowledge and skills. While some sections of the SEF covered very general areas of feedback, e.g. satisfaction with accommodation, catering and communication, for the purpose of this article, the two most relevant sections, i.e. sections 3 and 4 of the 2013 SEF, are explored in detail.

Sections 3 and 4 of the SEF explored teacher thinking about science teaching and student learning. These sections required teachers to respond to a series of statements using an incremental scale from 1–5, with 1 indicating a low level of knowledge and skill about science teaching and learning moving through to 5 indicating a high level. Teachers were required to complete a SEF before beginning the program and then again at the completion of the program. Each time, they were asked to plot their thinking in relation to the same statements using the same incremental scale. In this sample based on cohort size, N=55.

By collating and comparing responses at each incremental point before and after the program experience, it was possible to gain an overall impression, i.e. across the cohort, of progressive/regressive movement along the incremental scale. Such movement indicated either a positive or negative shift in teacher thinking in relation to science teaching and student learning.

Changes in Thinking About Science Teaching

In section 3, teachers were asked to respond to a range of statements about their own knowledge and skills in relation to teaching science. The data samples taken from these sections were collated and analysed in terms of the overall changes indicated by this cohort using the five-point incremental scale. Table 1 contains the range of statements and the cohort ratings both before and after attending the CAPS program. The table outlines the base number of responses for each statement and the number of responses assigned to each incremental point. As indicated in the table, not all 55 respondents chose to respond to each statement.

The SEF information provided numerical data making it possible to identify if teachers felt that program experiences had enabled them to experience a degree of change in their professional thinking, and this was represented as progressive/regressive movement in points along this incremental scale. The data analysis illustrated that as a result of program experiences, the majority of teachers indicated they were thinking differently about aspects of science teaching. In response to statements in this section on average, 24 teachers moved one to two points progressively along the incremental scale; 22 teachers moved two to three points progressively along the scale; 7 teachers showed no change and 2 teachers moved over three points progressively on the scale. Figure 3 outlines this information in detail.

Table 1 SEF results indicating teachers' self rating of personal knowledge and skills about teaching science before and after the CAPS program

Statements	Teacher response before/program	Total	Key: level of knowledge and skills relating to teaching science		
			Low (1–2)	Medium (3–4)	Excellent (5)
Teaching science as a way of thinking and acting.	Before	53	30	22	1
	After	53	0	27	26
Implementing effective pedagogy in primary science.	Before	54	26	28	0
	After	54	0	41	13
Linking science teaching to everyday life and world events.	Before	54	30	21	3
	After	54	1	19	34
Working with all areas of science.	Before	54	34	18	2
	After	54	3	39	12
Planning to link science knowledge and skills with learning in other curriculum areas.	Before	55	36	18	1
	After	55	0	35	20
Developing scientific literacy as an outcome for all students.	Before	55	36	18	1
	After	55	1	39	15
Assessing students as effective learners in science.	Before	55	32	22	1
	After	55	0	48	7
Supporting colleagues to develop effective pedagogy in primary science.	Before	55	40	15	0
	After	55	1	43	11
Identifying the absence/presence of school-based structures required supporting effective science teaching and learning at all levels.	Before	53	31	22	0
	After	53	3	36	14
Developing a strategic plan for school-based action to develop and sustain effective science teaching.	Before	55	39	16	0
	After	55	2	42	1

Changes in Thinking About Student Learning

In section 4 of the SEF, teachers were asked to respond to a range of statements about their own knowledge and skills in relation to student learning, e.g. developing students as confident participants in a constantly changing world, enabling students to understand the impact of

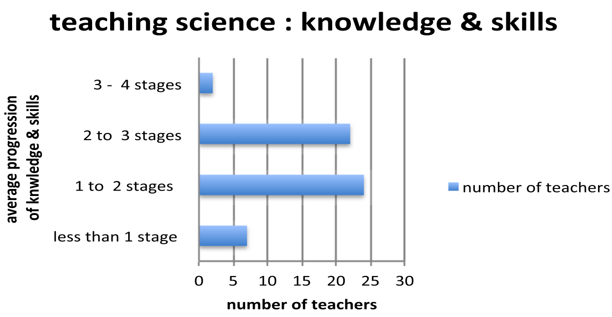

Fig. 3 Incremental changes in teacher knowledge and skills in relation to science teaching

science on society, etc. The data samples taken from these sections were collated and analysed in terms of the overall changes indicated by teachers in this cohort again using the five-point incremental scale. Table 2 contains the range of statements and teacher ratings of their personal competency in relation to each both before and after attending the CAPS program.

As with section 3, the SEF information illustrated that as a result of program experiences, the majority of teachers felt they had experienced a change in thinking about aspects of student learning in science. A similar shift was also indicated in response to statements in this section of the SEF, on average, 31 teachers shifted their response one to two stages progressively along the incremental scale; 14 teachers shifted two to three stages progressively along the scale; 7 teachers showed no change; and 2 teachers shifted over three stages progressively along the scale. Figure 4 outlines this information in detail.

It is interesting to note that in both sections of the SEF where teachers indicated no change, in all cases, teachers had indicated medium to high entry levels of knowledge and skills in the categories in this overall area. A pattern emerged across both sections of the SEF between teachers' self-assessment of high entry levels and little progress as a result of the program experiences. This could indicate that their thinking may not have been significantly altered as a result of the program experience or as a result of a significant SEF design fault, i.e. the incremental scale, teachers were unable to indicate further change in thinking.

Another limitation of this data, unlike the qualitative STaL data, this information was purely a statistical snap shot and does not provide an insight into what such incremental movements mean in terms of how individual teacher thinking changed. However, this information does indicate that teachers were aware that their thinking about aspects of their science teaching had changed since entering the program and attributed this shift to program experiences.

Implications of These Findings for Future Directions

Overall, the data indicated that the CAPS program had provided significant learning opportunities for teachers that enabled them to think differently about science teaching and their expectations of student learning. Working within a program, which positioned science teaching as an interdisciplinary endeavour in the primary setting, appeared to support primary teachers to think about pedagogical approaches that embraced a meaningful purpose for science teaching and learning. These findings suggest that providing learning opportunities for primary teachers, which enable science teaching and learning to be explored in this way, may increase teacher confidence with planning and teaching. This research may also provide impetus to support the development of strategic approaches, which aim to challenge the accepted and embedded silo approaches to science education beyond the primary school context.

Building Future Directions in Science Education

The information outlined in this article illustrates the types of strategic approaches that provide opportunities for teachers to experience meaningful and relevant professional learning in science education. Both programs represent in-service education initiatives that have successfully created learning conditions where teachers were acknowledged and enabled as those best placed to determine the types of changes needed in science pedagogy to enhance science education in their schools. The data illustrates that teachers gain significant benefit when professional learning opportunities value, respect and empower their expertise as science

Table 2 SEF results indicating teachers' self rating of personal knowledge and skills about student learning in science before and after the CAPS program

Statements	Teacher response before/program	Total	Knowledge and skills relating to students as learners of science		
			Low (1–2)	Medium (3–4)	Excellent (5)
Developing students as confident participants in a constantly changing twenty-first century world.	Before	54	15	37	2
	After	54	0	39	15
Developing students' appreciation of science as a way of knowing about the world.	Before	54	29	22	3
	After	54	1	27	26
Utilizing science to develop students' sense of awe and fascination about the world.	Before	53	18	34	1
	After	53	1	35	17
Enabling students to understand the impact of science on society.	Before	54	32	21	1
	After	54	0	41	13
Providing students with opportunities to accept responsibility towards the natural environment.	Before	53	13	38	2
	After	53	0	26	27
Enabling students to understand that science is influenced by cultural perspectives, often contentious and may be biased by personal values.	Before	54	32	21	1
	After	54	0	41	13
Enabling student to engage with science as accessible and doable.	Before	54	24	28	2
	After	54	0	34	20
Developing students' critical thinking skills through science	Before	54	26	27	1
	After	54	0	39	15

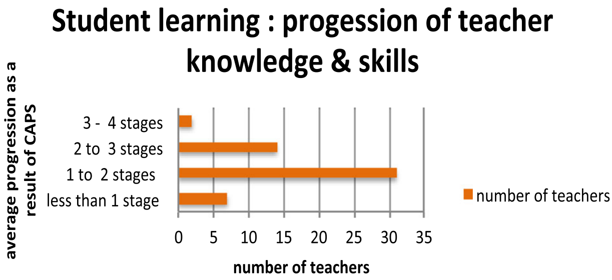

Fig. 4 Incremental changes in teacher knowledge and skills in relation to student learning in science

educators and assist them to engage students in quality science learning. Such strategic intent appears to contribute to teacher self-efficacy and agency.

As evident in the STaL data, teachers are willing to interrupt their accepted teaching routines to trial alternative teaching approaches but only if they think such action will enhance student learning. Therefore, providing opportunities that expose teachers to new thinking, e.g. exploring interdisciplinary approaches to enhance science learning, may be invaluable to ensuring that future science education is contemporary, relevant and engaging for all students. The data discussed in this article not only reinforces the important role of teacher professional knowledge of practice in all aspects of science teaching and learning but also begins to strategize data collection methods, which invite teachers to consider changes in their own thinking and how this might be captured. This raises considerations for the future of quality science education and suggests that teachers may benefit from continued operational support, which continually works to explicate their pedagogical reasoning and professional knowledge.

Conclusion

Reviews of existing science professional learning programs, such as that discussed in this article, potentially inform the development of a new strategic vision for science education, particularly in relation to teacher professional learning. This new vision supports teachers to articulate their own learning needs while they are actively working to determine what matters for their students in terms of professional practice. The findings discussed in this article support a compelling argument that learning conditions matter in teacher learning programs and that it is ultimately beneficial for all providers to regularly scrutinise current practice to ensure programs provide opportunities where the teacher is always positioned as an active and empowered learner; the complexity of teacher professional knowledge is acknowledged and valued in all aspects of program planning; teachers are positioned as pedagogical leaders in science education; science teaching is reframed as an interdisciplinary endeavour and careful consideration is given to determining useful 'evidence' of teacher thinking and educational change.

Professional learning has the potential to ultimately enable teachers find contextually relevant ways to build student curiosity and utilise big socio-scientific questions and privilege human endeavour and the enigmatic as an essential characteristic of the nature of science. Future in-service professional learning opportunities in science education have so much more to offer teachers beyond simply more science content and activities. Programs can continue to support teachers to actively explore a holistic view of science learning, so they decide how to best utilise their own teaching expertise and when and where to draw on support from a range of sources to provide science education that is authentic, purposeful, stimulating and engaging. This is particularly important for primary teachers who, from a generalist perspective, bring great pedagogical strengths to science teaching. As evidenced so strongly in the STaL program, science teachers at all levels benefit from working in partnership, as collaborative researchers, with academics. In this context, they begin to explore and develop their pedagogical reasoning to explicate expert practice. With appropriate sector support, future opportunities for teacher learning may ultimately position teachers as professional leaders in science education. While such intentions for teacher learning present inherent challenges to existing practices, the potential to improve student learning should be the incentive to continually explore, research and develop a range of alternative approaches.

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