Chapter 21
Science Teacher Learning

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Introduction

The recognition of the central place of teacher learning in school reform is a recent phenomenon. As Marilyn Cochran-Smith and Kim Fries (2008) suggest, we have seen the evolution of teacher development from being seen as a curriculum problem (1920s–1950s) to a training problem (1960s–1980s) to a learning problem (1980s–2000s) to a policy problem (1990s–present). Over the past 20 years, there has also been a developing interest in the nexus between student learning and teacher learning (Sykes 1999) and the notion of teaching as a learning profession (Darling-Hammond and Sykes 1999). Building on the work of Peter Senge (1990) and others, the crux of this argument is that schools, more than most organisations, are in the business of learning, and that all members of the organisation, administrators, support staff, teachers and students, should operate in an environment where learning is actively and explicitly valued and supported. Rather than seeing teacher learning as the effect of teacher development, this new perspective sees learning as *both* effect *and* affect: teachers learn as students learn and students learn as teachers learn.

In this chapter, we focus our attention on science teacher learning. Our perspectives are informed by literatures from fields as diverse as psychology, sociology, teacher development, school effectiveness, curriculum change, organisational change, and science and mathematics education. We are interested in theories of teacher learning, the nature of science teachers' professional knowledge, science

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teacher learning through teacher research, the relationship between student learning and teacher learning, and the contexts for science teacher learning.

Theories of Teacher Learning

Theories of science teacher learning can be characterised by various images of teachers' work – including the metaphors of computer, craft and complexity (Mullholland and Wallace 2008). Under the *computer* database metaphor, the teacher is seen as a consumer of a wide range of discrete professional development offerings, with each offering being designed to add (or plug in) an additional component to the teacher's knowledge base. Such a model is contextually agnostic and knowledge acquisition is seen as a logical manipulation of symbols within the individual mind. Under the *craft* metaphor, the teacher is an independent artisan, gradually building a repertoire of practice-based knowledge and skills through cognitive apprenticeship. The *complexity* metaphor sees the teacher as a social being working in particular societal, school and classroom contexts and communities. According to Dominic Peressini and colleagues (2004, p. 69), knowledge acquired under this metaphor is specific to those settings and learning is viewed as 'changes in participation in socially organized activity'.

These three metaphors can also be viewed as points on a continuum between an individual-cognitive perspective in which knowledge and beliefs are the primary factors that determine action, and a collective-situative one in which 'knowledge and beliefs, the practices that they influence, and the influences themselves, are inseparable from the situations in which they are embedded' (Peressini et al. 2004, p. 73). Theorists from the individual-cognitive end of the range could include Jean Piaget (1965) (cognitive development), Fred Korthagen and Jos Kessels (1999) (gestalt theory), Ernst von Glasersfeld (1995) (radical constructivism) and, from the situative-collective end of the range, Lev Vygotsky (1978) (cultural-historical psychology), Jean Lave and Etienne Wegner (1991) (situated learning and communities of practice), Ralph Putnam and Hilda Borko (2000) (situated knowing), Marlene Scardamalia and Carl Bereiter (2003) (knowledge building), Edwin Hutchins (1995) (distributed cognition) and Paul Ernest (1998) (social constructivism). Concomitant approaches to teacher development include (from the cognitive end of the range) professional development workshops and conceptual change strategies, and (from the situated end of the range) problem-based learning, case methods, teacher self-study, action research and collaborative learning communities.

Science Teachers' Professional Knowledge

Learning theories and strategies aside, there is general agreement that science teachers' learning needs to focus on improving teachers' professional knowledge. The literature is replete with different ways of thinking about that which comprises teachers' knowledge (e.g. Clandinin and Connelly 1995; Fenstermacher 1994). Sandra Abell's (2007) review of research on science teacher knowledge illustrates how the shift from research *on* teachers (1960s and 1970s) to research *with* and *by* teachers (1980s) led to a serious focus on the nature of teachers' knowledge as opposed to how well teachers do their work. This shift led to a greater appreciation of teaching as something more than the simple delivery of information and highlighted the importance of knowledge of teaching in moving beyond transmission models of practice.

While there is much agreement about the importance of teacher knowledge, there is also considerable discussion and debate about how teacher knowledge is constructed, organised and used (Feldman 2002; Fenstermacher 1994). In a longitudinal case study of one teacher of science, Judith Mullholland and John Wallace (2008) attempted to portray a range of different, though related, teacher knowledge representations. As mentioned earlier in the chapter, the metaphors were

> … teacher knowledge as *computer*, whereby knowledge is viewed as an interactive database or sets of skills and understandings; as *craft*, whereby teachers are seen as artisans whose skills exist in accomplished performance against a backdrop of the teaching context; as *complexity*, whereby knowledge is developed in complex interaction with the total environment and inseparable from this environment; and as *change*, whereby knowledge grows, evolves or develops over time. (p. 42, original emphasis)

This study, like many others concerned with knowledge of teaching, inevitably involved the concept of pedagogical content knowledge or PCK (Shulman 1986, 1987). PCK, is 'subject matter knowledge for teaching' – an amalgam of knowledge of content and knowledge of practice, brought together in a particular way through the specialist teacher's expertise (Shulman 1986). As the literature continually demonstrates, PCK appears to resonate strongly with scholars concerned with researching knowledge of practice – but perhaps none more so than in science. PCK offers a lens into the complexity of science teachers' professional knowledge in ways that draw attention not only to teacher learning, but also to how that learning might be recognised in, and influence the development of, practice. In recollecting how he arrived at the concept of PCK, Lee Shulman explained:

> I understood how complex it was to teach and learn that set of [Biology] ideas … Because [in Biology] you've got to deeply understand what it is that makes evolutionary theory…, whether you think ecologically or cellularly, what makes it difficult, and then what the variety of misunderstandings students might have, with the resilience of their misunderstandings. … They'll pass your test and then three weeks later you… ask them to: 'Explain the idea of bacteria that develop a resistance to antibiotics' and they'll give you a classic Lamarckian interpretation. … There's a big idea that's sitting in the middle of the field [PCK is therefore evident in how a science teacher recognizes and responds to such a situation]. (Berry et al. 2008, p. 1276)

PCK has been interpreted and studied in many and varied ways (Gess-Newsome and Lederman 1999). However, despite its allure to academics, it only really makes sense to teachers when it becomes 'real' and moves from an abstract concept to a concrete, useable form of knowledge for practice. This is well demonstrated in the work of a number of scholars. For example, Appleton (Appleton 2006; Appleton and Harrison 2001) studied PCK in elementary teachers and illustrated how, for these teachers, PCK encompasses 'activities that work'. Likewise, PCK has been examined by van Driel and colleagues (1998, 2001) with pre-service chemistry teachers, by Pernilla Nilsson (2008) with pre-service elementary teachers, and by Kira Padilla and colleagues (2008) with university science teachers. Common to all of these studies is the way in which, through the lens of PCK, science teachers can learn about and, therefore, better value, their knowledge of practice.

A particular approach to making PCK concrete for science teachers is that of the CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional-experience Repertoires), which were developed by a team of science education researchers at Monash University (Loughran et al. 2004, 2006). This approach has been successfully used in many studies of the knowledge of science teachers, but particularly so by Jim Woolnough (2007) in his work with pre-service teachers and Marissa Rollnick and colleagues (2008) with in-service teachers. In each of these studies, it is clear that participants frame their knowledge of teaching in new ways as a consequence of using a CoRe and PaP-eRs approach and situate themselves as learners and generators of knowledge of teaching. Such engagement in learning about teaching has been described by Robyn Brandenburg (2008) as reflective traction and can be a catalyst for more formalised inquiry into practice through teacher research.

Teacher Learning Through Teacher Research

Advocates such as Marilyn Cochran-Smith and Susan Lytle (Cochran-Smith and Lytle 1999, 2004; Lytle and Cochran-Smith 1991) have long argued that teacher research is an important cornerstone of educational reform. Although in many ways teaching might be described as involving ongoing inquiry into practice, it is through the more formalised approach of teacher research that teacher learning is able to move beyond the individual practitioner and be accessible and useful for others.

Many science teachers' initial forays into teacher research are as a consequence of apprehending the problematic in their own practice. John Wallace and Bill Louden (2002) drew attention to the problematic nature of teaching when they worked with science teacher researchers to explore the dilemmas of teachers' own practice through case writing. The notion of dilemmas is important because, as dilemmas are managed rather than resolved, teacher research based on dilemmas inevitably opens to scrutiny the myriad of decisions that teachers face in constructing meaningful learning experiences for their students. This work, like that of others working in the field of case writing (e.g. Lundeberg 1999; Shulman 1992) offers insights into one form of teacher research that begins to 'unpack' the complexity of teaching and learning.

Cases have proved to be an effective way of supporting and disseminating the learning from teacher research. For example, Berry and colleagues (2009) conducted a longitudinal study through which science teacher researchers published their cases. Berry's analysis suggests that, as a consequence of the careful attention to the detail necessary to write a case, many authors come to see into their classrooms in new ways, which itself then becomes an impetus for change. She illustrates how cases can empower teachers by opening up possibilities for dialogue about practice in ways that encourage and support risk-taking in practice – which is at the heart of learning from experience. Case reading and writing invites professional scrutiny and highlights the value of articulating knowledge of teaching which further supports teacher learning.

In a similar vein, Louden and Wallace worked with groups of teachers to focus on *specifics* (of teaching, often involving cases), on *standards* (of teaching and learning), on *quality conversations* (focused on teaching and with colleagues) and on *contexts* (structured formal and informal learning situations). In one example provided by Bill Louden and colleagues (2001), a group of experienced science teachers met regularly with academic collaborators over a 2-year period in a cyclic process of data collection, discussion and practice. Teachers videotaped their own classrooms, came together with colleagues to discuss their teaching videos in relation to a set of professional standards, and returned to the classroom to try some new ideas. The video segments, colleague commentaries and other artefacts were also assembled into a set of multimedia video cases for use as source material for further discussion.

Through case writing experiences, some science teachers have developed rigorous and systematic research into their practice and/or their students' learning. An example of this is to be found in the work of Ian Mitchell (1999), co-founder of the Project to Enhance Effective Learning (Baird and Mitchell 1986; Baird and Northfield 1992) and the subsequent Perspective and Voice of the Teacher (Loughran et al. 2002). These two influential projects involved science teachers documenting and learning from their own practices and collaborating in the hope that the same might happen for others. As a teacher researcher, Mitchell recognised that

> [t]eachers want to see classrooms via credible, contextually rich accounts of specific incidents … that provide teachers with ways into either experiencing the problem (e.g., ways of uncovering students' alternative conceptions in science) or into starting to do something about it. The accounts need to provide advice and ideas that will allow readers to experiment at different levels of risk. Accounts that gloss over difficulties and present stories of unmitigated triumph are unlikely to be credible to teachers… Communicating teacher research, in accessible and useful ways to other teachers involves some very different issues from those associated with communicating the same research to academics. (Mitchell 2002, pp. 263–264)

A common theme that emerges from teacher research is the value of teachers listening to, and therefore learning from, their students. The connection between science teaching and science learning should be such that they are not separate and distinct activities but partners in a symbiotic relationship. Therefore, just as it is anticipated that students learn from their teachers, so too it should be expected that science teachers learn from their students.

Teacher Learning Through Student Learning

Any serious examination of the notion of teacher learning must consider the reflexive and synergistic relationship between students' learning and teachers' learning. There are two ways to approach this subject, from science teachers to their students (as has been attempted by Kwang Yoon and her colleagues, 2007) or from students to their teachers. Here we chose to focus on the latter approach, that is, how science student learning can influence science teacher learning. The starting point for this approach is student science learning.

In their review of students' understanding of science concepts, Phil Scott et al. (2007) explained the roots of the field of 'alternative conceptions', moving from Piaget through to the influential work of Ros Driver (1983) and Roger Osborne and Peter Freyburg (1987). Much of the learning from this field has been captured in Helga Pfundt and Reinders Duit's (2000) *Bibliography: Students' alternative frameworks and science education*. However, knowing about students' conceptions, and doing something about it in practice are not necessarily the same thing.

In the final chapter of their influential book, *Learning in science: The implications of children's science*, Roger Osborne and Peter Freyberg (1987) consider what it means to introduce children's ideas of science to teachers.

> When we have talked to fellow teachers and teacher educators … [Some colleagues] have initially found it difficult to accept that their assumptions about what children interpret from their well-prepared lessons could be so different from what they (as teachers) intended. … When teachers become aware of children's ideas on the consequential difficulties pupils can have in learning science, they experience conflicting feelings as to what they can do about it. (p. 136)

Helping teachers to find appropriate ways of responding to children's ideas was the focus of the Children's Science group, initiated by Dick Gunstone (1990). The group was comprised of elementary and secondary science teachers who met on a regular basis with academic collaborators. Over a decade of work, the group developed and documented new teaching procedures designed to approach practice by taking into account students' prior views and/or to challenge students' thinking about science phenomena.

As the work of the Children's Science group demonstrated, listening to and learning from students focuses attention on the notion of meta-cognition:

> [Metacognition is the] amalgam of learner knowledge, awareness and control of their learning … [it] is learned, and so can be reconstructed if the learner is willing and able. It is not, however, in any way easy to have learners do this. It requires recognition of existing views, evaluation of these views, and then learner decisions about whether or not to reconstruct. … If the learners' ideas and beliefs about the processes of learning and teaching are in conflict with them recognizing, evaluating, reconstructing their existing science ideas and beliefs then little progress is possible. (Gunstone 1990, p. 17)

Meta-cognition is important not only to student learning but also to teacher learning. Clearly, just as students need to act meta-cognitively if they are to confront and reconstruct their conceptions of science, so too science teachers need to pay careful attention to that which is occurring in a classroom situation and to actively respond to what they see, hear and do, in a pedagogically appropriate way. Being sensitive to the 'student voice' is a fundamental element that underpins quality in science teaching.

Similarly, Robin Millar (2006) draws attention to the value of inviting students into their own learning of science through the notion of engagement. He suggests that, through a careful consideration of engagement, teachers can facilitate students' science learning by helping them to make powerful links between the science that they learn in school and the science that they know about from their out-of-school experiences. Again, the importance of recognising the synergies in teaching and learning are crucial here as exemplified Keith Bishop and Paul Denley's (2007) book. In their chapter on 'student voice', the authors show how science teacher learning is inextricably linked to learning from students:

> Our view is that it would seem odd to make no attempt to find out, or even be aware of, what the students you teach think of their science education or what they expect from it. … [T]he evidence suggests that the student voice offers exciting possibilities to innovative and creative science teaching and enhanced student engagement. From our own research, and from research in the public domain, we advocate that listening to students is an essential part of any science teacher's professional learning. (pp. 167–168)

It naturally follows that the way in which the practice setting is organised and structured influences not only how teachers learn, but also what they learn and what they do as a consequence of that learning. Therefore, the contexts in which teachers work and learn require just as much attention as the nature of that learning if the conditions for learning are to be supported and enhanced.

Contexts for Teacher Learning

What are the appropriate contexts for teacher learning? How can science teacher learning be nurtured and encouraged? For a simple answer to these questions, we might look at the recent empirical literature on 'reform' style teacher development to identify characteristics such as connection to the classroom, sustainability, collective participation, focus on content and student inquiry, active learning and coherence (Garet et al. 2001).

Another approach is to examine the typologies of teacher development strategies suggested by the individual-cognitive and the collective-situative, with the individual typified by out-of-school and workshop-style offerings and the collective characterised by in-school and collaborative activities. The advantage of the individual approach is that generalised solutions to curriculum problems can be identified and widely disseminated. Further, teachers can pick and choose offerings depending on their perceived needs and motivations. The disadvantage is that these activities are typically not grounded in the teacher's practice, and are often conducted in isolation from the communities that they are intended to serve. While collective approaches are more locally effective, they are often complex and unwieldy and suffer from a lack of transferability. However, as Dominic Peressini and his colleagues (2004) point out, the individual-collective dichotomy is misleading because the relationship between classroom practices and individual reasoning is reflexive. 'Students contribute to the development of practices within the classroom; these practices, in turn, constitute the immediate context for [teachers'] learning' (p. 71).

A further dimension to this discussion is offered by Lee Shulman and Judith Shulman (2004), co-investigators of the Fostering Communities of Learners programme. In attempting to fathom and explain the different learning experiences of two Grade 8 science and mathematics teachers, the authors concluded that, in order to learn, a teacher must be ‘Ready (*possessing vision*), Willing (*having motivation*), Able (*both knowing and being able “to do”*), Reflective (*learning from experience*), and Communal (*acting as a member of a professional community*)’ (Shulman and Shulman 2004, p. 259, original emphasis). As the authors point out, these attributes – readiness, willingness, ability, etc. – have both an individual and a collective component. ‘The individual and community levels are both interdependent and interactive’ (p. 267). They conclude: ‘While the “subject matters” in these settings, there is so much more going on simultaneously that at times the ever-important content differences can be swamped by other critical features of the context’ (p. 269).

Like many other scholars, we favour a pragmatic model of teacher learning that incorporates both theoretical positions. Paul Cobb and Janet Bowers (1999) talk about the ‘choice between any particular case being a pragmatic one that depends on the purposes at hand’ (p. 6). Such a position highlights the interrelatedness of elements within systems, and the notion of ‘individual-in-social-action’ used by Gary Hoban (2002) to represent the interaction of the cognitive and the situated.

A pragmatic perspective would suggest that teachers need the opportunity to engage in authentic activities, participate in rigorous and critical debate within discourse communities, and develop facility with the various tools used in that community. Often, these conditions are not always available in the one place. While authentic activities are most often associated with the classroom and the school, it is difficult for teachers to break out of routine ways of teaching, especially as schools do not always value or support critical and reflective practice. The more sophisticated cognitive, cultural and language tools of practice are often to be found in discourse communities outside the school – for example, in professional associations, universities and district and central offices. Moreover, organisational learning and learning across the profession are more likely to proceed if teachers also engage in communities beyond the four walls of the classroom.

We argue that supporting teacher learning entails the creation of formal and informal opportunities for learning to proceed in multiple contexts (settings, communities and learning foci). Deborah Ball and David Cohen (1999, p. 25) refer to a ‘pedagogy of professional development’ that comprises of the tasks and materials of practice, the discourse to support learning with these tasks and materials, and the roles and capabilities of leaders who provide guidance and support for this work. In this chapter, we have provided several examples of locally managed teacher development linked to other discourse communities, such as universities and school boards. The strength of these systems models is in the bringing together of the various components of the science education enterprise – students, teachers, teachers’ knowledge, school leaders, research-based inputs, academic and systemic supports, etc. – in such a way as to build local relevance and ownership while developing both individual and organisational learning.

Conclusion

Teacher learning is, we maintain, a central tenet for educational reform. In this chapter, we argue for a model of teacher learning that encompasses both the individual-cognitive and the collective-situative stances on learning. This position recognises that teachers operate as individuals, making choices about levels of engagement, processing information and reflecting and acting on that information. Also teacher learning is inextricably linked to the learning of others – to students' learning, colleagues' learning and organisational learning.

We favour an approach to teachers' learning that focuses on research with and by teachers, on building teachers' knowledge about teaching and for practice, and capitalises on the inextricable connection between teachers' learning and students' learning. Such learning takes place in multiple learning contexts, combining out-of-school activities, theory and practice-based learning experiences with ongoing support for teachers to learn from their students and to integrate ideas into their classroom practice. In this chapter, we have described some promising examples of teacher learning, including action research projects, case writing, video clubs and content representation among others. These models have individual and collective components. They foster classroom-based, teacher research within a context of theory-driven ideas and collegial and other support. They also attempt to build a discourse community around science education, not only across the school but also in the wider school community.

Simply stated, teacher learning is about teachers building and sustaining knowledge of classroom practice across various discourse communities. It includes principles such as teacher ownership, focus on practice, coherence, collegiality, active learning and systemic support. Putting these principles into practice, however, is a different story. Teacher learning is complex because it is about the complicated interplay between the individual and the collective. In this chapter, we have argued for a model of teacher learning that acknowledges this complexity, and that marshals the various components of the science education enterprise to respect and support teachers' attempts to build knowledge of their own practice.

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