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Pedagogical Content Knowledge (PCK): Exploring its Usefulness for Science Lecturers in Higher Education

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Abstract In the past 30 years, pedagogical content knowledge (PCK) frameworks have become important constructs in educational research undertaken in the school education system and a focus for research for curriculum and teacher education researchers. As regards science, PCK research has been plentiful, but thus far, the concept of PCK (significantly enhanced since its proposal) has only been validated in the school context (Kindergarten to Grade 12). Within this environment, however, it has proven to be a very useful construct for understanding teacher practice and contributing to the improvement of teacher education courses. Knowledge about whether PCK is useful as a conceptual framework for science lecturers (teachers) working in higher education is as yet unknown and represents a gap in the research literature; the research outlined here is a first step in exploring its usefulness in this context. This paper provides an analysis of data obtained from semi-structured interviews conducted with nine Australian science university lecturers from various disciplines and levels of seniority and experience of tertiary teaching, as well as an academic developer skilled in facilitating science academics' understanding of pedagogy in higher education. The research aimed to investigate the extent to which one version of a school-based science PCK framework resonated with the pedagogical thinking of university science lecturers and the ways in which it could influence their teaching practice.

Keywords Science · Pedagogical content knowledge · University teaching · Conceptual frameworks

Teaching and Learning in Higher Education

Science teaching at university continues to face serious challenges, including poor retention or enrolments into senior secondary school science and advanced level mathematics (Ainley et al. 2008), poor preparation of students coming from schools (Tytler 2007) and the decline in students' interests in and attitudes to science as they progress through secondary school (Barmby et al. 2008; Sjoberg and Schreiner 2005). These challenges result in too few undergraduate students enrolling and persisting in science degrees (McMillan 2005; Olsen 2008) and then once

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students who plan to study science arrive at university, the quality of the science instruction they receive is variable (Fox and Hackerman 2003; Sunal et al. 2004). Academics who are interested in improving the quality of their teaching often experience powerful disincentives to doing so; teaching enhancement activities are generally held in low esteem and there is often little reward for such efforts (Seymour 2002). Although money is often available for discipline-based educational research (DBER) in science, Sullivan (1991) argues that to bring about meaningful reform, it is more important that efforts are "based on a driving vision of what works" (p. ix). What is it that "works" in university science education and what conceptual frameworks guide the practice of interested science academics and enable them to recognise and discuss effective or excellent teaching?

Excellent (effective) teaching has been described as "that which produces learning and understanding" (Murray attributing Socrates 1994, p. 380), and in order to determine whether student learning has been enhanced, teachers must evaluate their practice. Academics interested in evaluating their practice or engaging in science DBER could call on any number of frameworks to inform their questions and teaching strategies, including literature relating to alternative conceptions (Driver and Easley 1978; Wandersee et al. 1994), conceptual change theory (Hewson 1981; Özdemir and Clark 2007), threshold concepts (Meyer and Land 2003), constructive alignment (Biggs 1996) and the teaching-research nexus (Healey 2005a; Neumann 1992). However, research that is undertaken in schools, along with the theoretical and conceptual frameworks that are useful in school-based teaching, is rarely interrogated by university staff. School-based literature, understandings or practices and the principles that underpin good learning, good teaching and/or good learning environments derived in this context have little influence on practice in universities. This paper reports on a study focussing on an influential construct in the school sector, Science Pedagogical Content Knowledge (PCK), and the extent to which university science lecturers perceive it as a relevant and useful framework for thinking about their teaching and curriculum development.

Pedagogical Content Knowledge

Almost 30 years ago, Lee Shulman stated that a "missing program" in educational research may be the study of teacher *pedagogical content knowledge* (PCK) or "teachers' cognitive understanding of subject matter content and the relationships between such understanding and the instruction teachers provide for students" (1986a p. 25). Since that time, researchers have honed Shulman's ideas to the extent that his construct now forms the basis for both understanding how teachers work and how they are educated to become teachers. PCK is viewed as one component of teacher knowledge as indicated in Grossman's (1990) model of the domains of teacher knowledge (Fig. 1). This model proposes that PCK both influences and is influenced by the teacher's subject matter knowledge, pedagogical knowledge and knowledge of the context within which they are teaching.

Although educational researchers still debate the relative importance of each of these domains, how PCK is transformed through experience and the extent to which the PCK components interact, support for PCK as a concept remains strong. It has become an important construct, therefore, in educational research and improvement initiatives undertaken in the school sector. Educational researchers have used it to study science teachers' practice and to improve teacher education courses (e.g. van Dijk and Kattmann 2007), explicate teacher practice (e.g. Loughran et al. 2003), identify domain-specific PCK (Bucat 2004), and map, assess and measure (elements) of PCK (e.g. Olszewski et al. 2009; Park and Chen 2012). Some researchers have also used it to study the expertise and practice of university science

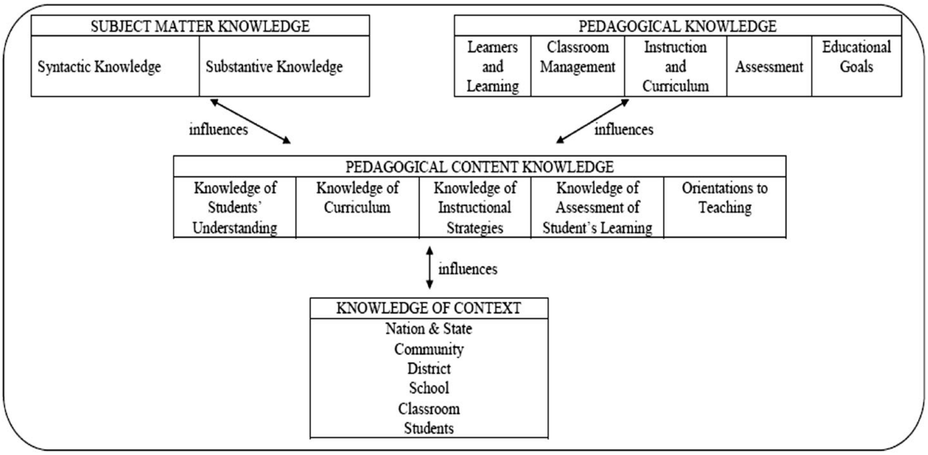

Fig. 1 Model of relationships amongst the domains of teacher knowledge (Grossman 1990)

lecturers (Padilla et al. 2008), the relationship between components of PCK (Padilla and van Driel 2011) and college students' perceptions of lecturer PCK (Jang et al. 2009). PCK as a concept, however, is not a familiar one for science lecturers, and the extent to which it is useful to them as a conceptual framework is as yet unknown. It is possible, therefore, that PCK might assist lecturers to interrogate their practice through a lens that also exposes them to the value of pedagogical study and the educational literature emerging from the school context.

The Framing of PCK in Science Teaching

According to Kind (2009), PCK researchers have interpreted and used Shulman's initial construct in a number of ways. Some remain aligned with Shulman's way of thinking (Grossman 1990; Magnusson et al. 1999) and maintain PCK separate from subject matter knowledge (SMK), or the amount of knowledge that a teacher has and how it is organised (SMK); whilst others include SMK within PCK (Ferndandez-Balboa and Stiehl 1995; Marks 1990). Gess-Newsome (1999) refers to the former model of PCK as transformative, as proponents believe that PCK is "new knowledge arising from the act of transforming subject matter, pedagogical and contextual knowledge for the purposes of instructing students" (Kind, p. 180). Kind refers to models that include SMK within PCK as integrative, as for these researchers, PCK "summarises a teacher's knowledge base, so does not "exist" as a separate type of knowledge" (p. 180). Kind argues that teachers are better able to understand, describe and develop their PCK when working with transformative models as they have more "explanatory power".

Kind (2009) highlights one model in particular, the Magnusson et al. (1999) model (Fig. 2), as being most useful for educating novice teachers to teach science effectively. The five categories incorporated into this model ally with those initially proposed by Shulman (1986b) and enable teaching practice to be explicated and potentially measured and improved. Thus, the Magnusson et al. model was the one chosen to share with science lecturers for the purposes of discussing PCK as a general construct, as a way of thinking about teaching specific topics and exploring its relevance and authenticity in their higher education context.

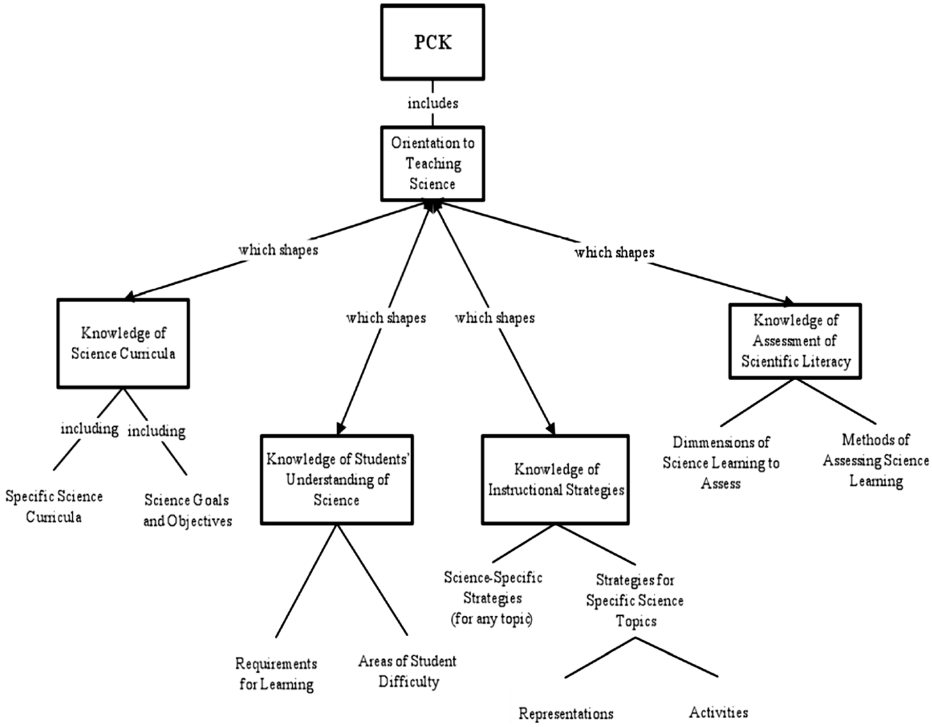

Fig. 2 Components of PCK for science teaching (Magnusson et al. 1999)

Orientation to Teaching Science

A central element of the Magnusson et al. (1999) model is the “orientation to teaching science” or “teachers’ knowledge and beliefs about the purposes and goals for teaching science at a particular grade level” (p. 97). The authors believe this element plays a central role in influencing the other four elements of PCK and therefore shaping teacher practice as a whole. Being such a critical aspect of the framework, science PCK researchers (e.g. Abell 2007) have highlighted it as a component deserving close examination. Two papers in particular enable a greater clarification of what is meant by science teaching orientations; firstly, Friedrichsen et al. (2011) provide clarification through their review of the empirical basis of the nine teaching orientation categories included in the Magnusson et al. model. They propose that teaching orientations encompass the following three dimensions: beliefs about the goals or purposes of science teaching, beliefs about the nature of science and beliefs about science teaching and learning.

The second study of note (Friedrichsen and Dana 2005) presents a substantive-level theory of science teaching orientations (Fig. 3), which identifies factors that influence the development of science teaching orientations. A key outcome of their study was a recognition of the contextual nature of teachers’ beliefs about teaching and the fact that they are often implicit and difficult to describe. The authors conclude that it is essential to elicit teachers’ beliefs, as their practice is “highly influenced by what they already know and believe about teaching, learning and learners” (Borko and Putnam 1996, as cited in Friedrichsen and Dana 2005, p. 240). Hence, enabling science teachers to identify their own understandings and beliefs about science teaching and learning referenced to the environment within which they teach is essential to their development of effective science PCK.

These two papers (Friedrichsen et al. 2011; Friedrichsen and Dana 2005) pertain to the school education sector, but it is possible to cross-reference them with studies with similar goals undertaken in the higher education context. Several studies undertaken by Trigwell and colleagues, focussing on the relationship between conceptions of (beliefs about) and approaches to teaching (Trigwell and Prosser 1996b) and teaching intentions and strategies (Trigwell et al. 1994; Trigwell and Prosser 1996a) in tertiary science, are worth noting. Their research shows great consistency between science lecturers' conceptions and approaches to teaching. For example, those who conceive of teaching as transmitting information to students also conceive of student learning as information accumulation and, therefore, incorporate teacher-focussed teaching strategies in their teaching. Trigwell and Prosser (1996b) speculate, as did Friedrichsen and Dana (2005), that it may be very difficult to change teachers' conceptions of (beliefs about) teaching and learning, but that such change is necessary for them to change their approaches to teaching. They also agree that environmental conditions are

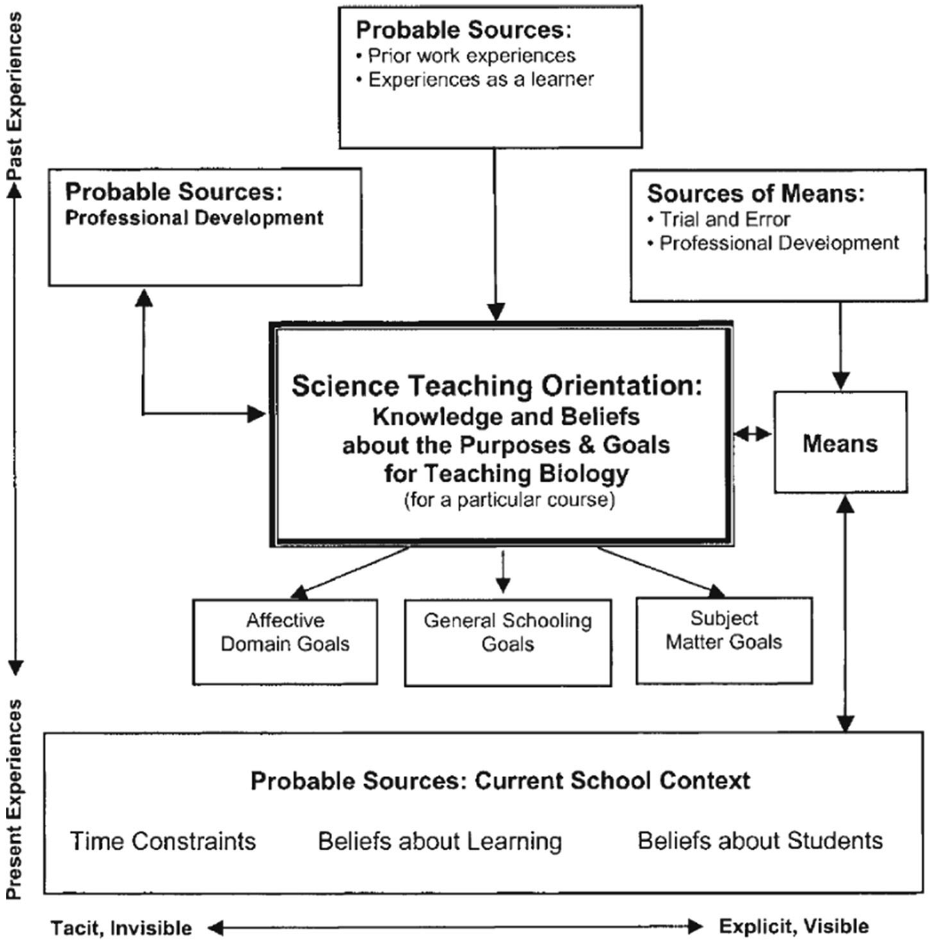

Fig. 3 Substantive-level theory of science teaching orientations posed by Friedrichsen and Dana (2005)

an important determinant of the teaching approaches adopted by lecturers. Considered together, these papers emphasise a congruence of teaching practices in school and tertiary education settings.

Whilst there are synergies between school and tertiary educational contexts, there is one major difference between them; in school settings, a teacher's main role is to teach, whereas in higher education, a lecturer is required to both teach and research. Lecturers often experience these two requirements as a dichotomy and "mutually antagonistic" (Barnett 2003, p. 157), and this dichotomy can impact on the level of attention lecturers give to their teaching.

Dealing with the Dichotomy of Teaching and Research in Higher Education

Many staff interested in enhancing their teaching practice and their students' learning have addressed the tension between teaching and research (Hattie and Marsh 1996) by researching their teaching, and drawing understanding from and contributing to the scholarship of teaching and learning (SoTL[1]) (Boyer 1990). Kreber (2005) summarises the role of SoTL as "… enhancing the quality (and recognition) of teaching and student learning institutionally and within the disciplines", and suggests that it should be "…informed by knowledge of the field, be inquiry-driven, involve critical reflectivity, and include scrutiny by peers" (p. 328). Proponents of SoTL in science publish their research outcomes and thereby contribute to their research quantum and fulfil the requirements of academic work. Thus, a consideration of SoTL for improved student learning (Vardi 2011) is essential to underpinning teaching improvements in higher education.

In addition to SoTL, the related literature focussing on the teaching-research (T-R) nexus (Neumann 1992) is also persuasive for academics and highlights challenges for both individual staff and institutions of higher education (Jenkins et al. 2003). Healey (2005b) has contributed significantly to academics' ability to conceptualise and operationalise the nexus whilst reshaping their curricula. Ideally, through focussing on the T-R nexus (Fig. 4), science lecturers would design learning experiences for their students that enable them to learn from and about scientific research (research-led and research-tutored),[2] learn in research mode (research-based)[3] through participating in inquiry-based learning and learn the skills required to undertake scientific research (research-oriented learning).[4] The T-R nexus presents a compelling conceptual framework for science lecturers as it aligns so well with their academic endeavours and the importance of research in their discipline. A focus on the T-R nexus and/or SoTL provides some academics with a research pathway that enables them to balance the competing demands of teaching and research.

If PCK is to be useful for academics, therefore, then the way in which it is represented must be appropriate to the higher education context, in harmony with the literature and understandings that are currently influential, and cognisant of the fact that academics are both time-poor and working within a complex and political context. It needs to be intuitive, resonating with experience and need, and be seen as contributing to outcomes that are perceived to be important, for example, improved unit design and student learning outcomes. The PCK

[1] Includes engagement with the literature around science pedagogy and learning from and contribution to SoTL and the advancement of scholarly science teaching through DBER.

[2] Incorporates content based on/in research: learning about other's research through incorporating current research into the content that is taught.

[3] Incorporates enquiry-based learning into the teaching context.

[4] Incorporates teaching strategies and learning experiences which help students understand research methods and what it means to undertake research in science.

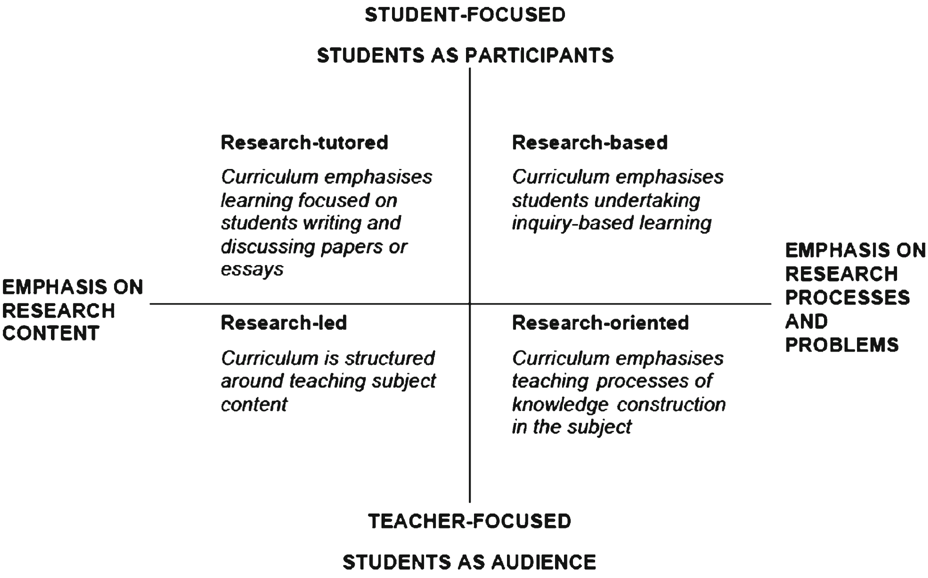

Fig. 4 Curriculum design and the research-teaching nexus (Healey 2005b)

construct was created for (with) teachers in school settings and has been validated and enhanced in this context; hence, an exploration of its usefulness to science lecturers is warranted.

The Study

The study reported here focussed on the extent to which PCK resonates with the practice and understanding of university science lecturers working in an Australian university considered competitive in both teaching and research endeavours. The research study was underpinned by an interpretivist paradigm (O'Leary 2009), as the researcher was interested in exploring the participants' experiences of teaching science and their responses to the framework presented to them. Interviews were chosen as the research method to enable dialogue and a joint exploration of participants' experiences and their emerging understandings.

The study sought to explore the following questions:

1. To what extent and/or in what ways does one version of a framework representing school-based science PCK resonate with the pedagogical thinking of university science lecturers?
2. To what extent and/or in what ways does the school-based science PCK framework have the potential to influence the teaching practice of university science lecturers?

These questions were explored with reference to how participants talked about their approaches to teaching (how they teach), their conceptions of teaching (their beliefs about teaching) and as regards any conceptual frameworks that influenced their pedagogical thinking and teaching practice. The interview questions (Appendix 1) were constructed so that they did not lead participants to any predefined outcomes but enabled them to explore their experiences of teaching and freely express their understandings and responses. The interview schedule was trialled with a colleague prior to being utilised with research participants. Member checking was subsequently employed to verify both the truthfulness of the transcription and the understandings expressed therein.

In order to investigate the research questions, science lecturers representing a range of science disciplines, teaching experience, curriculum development experience and levels of seniority were contacted and invited to participate in the research. Ultimately, eight science lecturers and one academic developer (Table 1) self-selected to participate in a semi-structured, face-to-face interview of approximately one hour.

The interviews were undertaken between August and December 2011 with the interview schedule incorporating questions relevant to the research questions and a discussion of the Magnusson et al. (1999) framework for PCK (Fig. 2). Participants were provided with the interview questions prior to the research meeting, whilst the PCK framework was introduced to them at the interview. In part A of the interview schedule, the researcher created space for each participant to speak freely about their backgrounds in both teaching and research and their understandings about and experiences of teaching science. Part B of the schedule commenced with the researcher presenting the PCK framework (Fig. 2) to the participant and working through the diagram in detail, explaining the meaning of each component and referring back to statements participants had made previously in part A if appropriate, in order to clarify or answer questions as they arose. All interviews were recorded, after which participant responses were transcribed, shared with participants and subsequently coded using nVivo software. Data analysis was distributed via email to participants for feedback, and the six suggestions for an enhanced usage of the framework in higher education received endorsement from all.

The research outcomes of the study are presented here in two parts; as indicated, part A focuses on an exploration of the ways in which science lecturers talked about their beliefs about teaching and learning and hence orientations to teaching science, the context within which they teach and any conceptual frameworks that guide their practice (research question 1). Whilst part B focuses on the extent to which the PCK framework resonated with lecturers, referenced to their beliefs about learning and teaching in science, and their

Table 1 Participant diversity by discipline, level of appointment and years of teaching

Pseudonym	Discipline	Academic level[a]	Years of teaching	Graduate certificate[b]
Paddy	Pharmacology	D	30	x
Miller	Analytical Chemistry	C	12	x
Mario	Microbiology	C	20	✓
Diane	Crop Science	B	5	✓
Janet	Endocrinology	B	9	✓
Peter	Astrophysics	D	11	✓
Bronwyn	Nutritional Biochemistry	C	1	x
Anna	Zoology	E	24	x
Liz	Academic Development	B	–	na

[a] A: Associate Lecturer, B: Lecturer, C: Senior Lecturer, D: Associate Professor, E: Professor

[b] Graduate Certificate in University Learning and Teaching—preparation for teaching; only the first unit is compulsory

thoughts on how the construct might be presented to lecturers for the purpose of enhancing practice (research question 2).

Interview Part A—Situating PCK: Science Lecturers' Beliefs About Teaching and Learning

Coding, analysis and interpretation of the data generated in response to the first research question were informed by two constructs:

1. the domains of teacher knowledge (Grossman 1990); and
2. the Magnusson et al. (1999) PCK construct.

The coding categories identified as potentially useful are shown in Table 2. Categories 1 to 5 are the PCK components identified by Magnusson et al., with category 1 benefitting from a clarification of the meaning of "orientations to teaching" (Friedrichsen et al. 2011). Category 6 featured very prominently during the interviews and relates to the domains of teaching (Grossman 1990), whilst the final category, "knowledge of the scholarship of teaching and learning (SoTL)" (including DBER) emerged from the interviews as an important consideration for effective university science teaching. The categories italicised in Table 2 were not identified in the research data and hence did not form part of the final coding structure. It is important to note that a discussion of beliefs about the nature of science (category 1 (ii)) may not have been elicited due to the characteristics of the interview questions, although participants' thinking in this regard was indicated implicitly in their responses to other interview questions, in particular their own "orientations to teaching". Equally, although assessment is a large component of both the workload and cognitive engagement of science lecturers, participants seldom mentioned this aspect of their teaching. When it was mentioned, it was usually only in regard to the overall trend of decreasing student abilities as indicated by their grades, rather than a component of the participant's pedagogy and an area that is pivotal to learning.

Interview Part B—Resonance of the PCK Framework

The second half of the interview focussed on the second research question and incorporated a discussion of the Magnusson et al. (1999) PCK construct (Fig. 2).

Table 2 Potential categories used for coding responses generated in part A of the study

Category
1. Orientations to teaching
i. Beliefs about the goals and purposes of science teaching
*ii. Beliefs about the nature of science**
iii. Beliefs about science teaching and learning
2. Knowledge of science curricula
3. Knowledge of students' understanding of science
4. Knowledge of instructional strategies
*5. Knowledge of assessment of science (literacy)**
6. Knowledge and beliefs about context
7. Probable sources of teaching orientations
8. Knowledge of the scholarship of teaching and learning (SoTL)

Italic entries were not identified in the research data and hence did not form part of the final coding structure.

Results

In the following sections, a summary of participants' responses for both parts A and B of the interview is provided, inclusive of indicative responses which contribute to a rich description of their orientations to teaching science, their teaching practice and responses to the PCK construct.

Interview Part A: Beliefs About Teaching and Learning

Orientations to Teaching

Beliefs About the Goals and Purposes of Science Teaching Participant responses included reference to both subject matter goals and general schooling goals with the latter being dominated by thinking informed by graduate attributes. All agreed that an understanding of content (topics) was not the sole driver for science teaching, rather such understanding provided the basis for students to be able to understand the nature of science or "apply the science" and "think like scientists" and engage in "disciplinary discourse" (Airey and Linder 2009, p. 27).

Beliefs About and Attitudes to Science Teaching: Students' Learning and Science Teaching A number of participants indicated that at the heart of their practice was a relationship with their students, expressing the belief that this contributed to the effectiveness of their teaching and their students' learning. Several mentioned the importance of students taking responsibility for their learning, as exemplified by the following quote:

> I am keener for them to go it alone for a little while, maybe come up with some of their own ideas that are not necessarily correct, but to continue to gather all of that evidence and then to…challenge their conclusions, so that they are the ones that have to realise where they've taken the wrong path. (Janet, Endocrinology)

All agreed that students needed to be engaged and active in order to learn, and such engagement was achieved through the lecture material and its delivery and importantly through the T-R nexus.

Whilst none of the participants challenged traditional science delivery methods, at least one admitted that traditional science teaching rarely takes account of differing learning styles, and Miller recognised that these structures might impact on students' understanding of science; saying:

> I think that's one of the real problems we have, we put the students in, you've got three hours to do the prac, they walk out at the end, they've got no understanding of what they've done, they don't get the opportunity to come back next week and try it again. (Miller, Analytical Chemistry)

The primacy of content knowledge was acknowledged by all; they felt that in order to teach well and take risks in the "classroom", you need to be on top of your content. As Janet summarised:

> …but initially I did, I think, fall back into a much more traditional didactic style, I wasn't able to ask the leading questions because I just didn't have enough knowledge around the idea or the topic. I think by now the students have asked me all the questions and… so I am more confident, I can take more chances and try different strategies in the lecture theatre and so on… (Janet, Endocrinology)

Whilst it was felt that content is the main focus for novice lecturers, more experienced lecturers indicated that being a content expert is not enough. As Peter explained:

> …it's all very well for me to know the content…but then you've got to work out how to make the students understand as much of that as possible… (Peter, Physics)

Knowledge of Science Curricula

Although participants all agreed that having appropriate academic content knowledge is essential to being an effective teacher, many acknowledged that they had been in teaching situations when they did not always have a sufficient level of expertise to teach. Several referred to strategies that they had developed which enabled them to be sufficiently "on top of the material" in order to teach it; whether these strategies were sufficient to achieve a specialised SMK was not clear. Nevertheless, academic content knowledge was at the heart of the curriculum decisions that they made, with a number of participants referring to the importance of having a broad knowledge of the ways in which the (science) disciplines inform each other (e.g. mathematics underpinning chemistry). Student diversity, entry levels and course pathways were important considerations in both curriculum decisions and ways in which the subjects are taught. One of the major guiding principles for curriculum development was a knowledge of course learning outcomes and the purpose of the degree and/or the needs of the science profession. The only conceptual framework that was mentioned as being influential in guiding such curriculum decisions was that of constructive alignment (Biggs 1996), and this was only mentioned by those who had undertaken the Graduate Certificate in University Learning and Teaching (see Table 1).

A synthesis of participant responses indicated that curriculum development is reasonably flexible and occurs in many ways, through holistic and critical reflection, focussing on the student cohort and in negotiation with colleagues or by trial and error. Curriculum may equally result from historical precedence—"it's always been taught like this"—or as a result of either mirroring the textbook or copying what is done across the sector. There was a common understanding of and commitment to research-led learning and curriculum development, a process which was felt to assist both students' learning and teaching effectiveness. As Diane explained:

> …because I've done research in it I can just draw on stuff so easily. And it just completely changes, I think, your delivery and probably even fortunately the confidence in the delivery because you've just got such broad areas to draw on and to bring them in, bring in examples and personal experience as well. I think that's … and they relate to that, I think, as well. (Diane, Crop Science)

Knowledge of Students' Understanding of Science

Knowledge of students' understanding of science was at the forefront of all participants' thinking; several acknowledged that students new to university have to learn both how to be university students, as well as gain access to the discipline's discourse. Peter acknowledged that understanding in science was constructed in particular ways; by building on foundational knowledge and through the development of what Mario referred to as "big ideas". Additionally, as concepts are often new, abstract and difficult to access, gaining knowledge of students' prior learning was pivotal.

The more experienced lecturers talked about their ability to anticipate student difficulties, acknowledging that teaching experience is the only thing that allows you to be able to do this successfully, as Peter summarised:

> …once you've done it more than twice you have a pretty good feeling for what are likely to be the problem concepts and where the weaknesses are likely to lie and so we tend to focus on addressing those. (Peter, Physics)

Such understandings align well with our understanding of PCK developing over time as lecturers' experience of the context and the nature of their students increase.

Knowledge of Instructional Strategies

Traditional science teaching instructional strategies (lectures, tutorials, laboratories and field work) were employed by all participants, and such choices were linked with both the learning outcomes they were trying to achieve and their perceptions of students' needs. The strategies that were chosen often aligned with the text used in the unit (subject) and "usual" discipline approaches across the sector and were somewhat dependent upon the lecturers' expertise in the content. Whilst a lack of content knowledge was acknowledged by participants as limiting, the relationship between pedagogical knowledge and willingness or ability to implement innovative instructional strategies was not made clear.

Knowledge of the Scholarship of Teaching and Learning

Whilst lecturers self-selected to participate in the study, thereby displaying an interest in learning and teaching, all admitted that the extent to which they accessed SoTL and/or engaged in regular pedagogical conversations was limited. Those who had participated in the Graduate Certificate in University Learning and Teaching (Table 1) had been exposed to some pivotal SoTL literature and felt that their exposure to such ways of thinking was essential to their current understanding and practice. As Janet summarised:

> …that [Grad Cert] actually gave me at least part of a framework into which I could insert all of this instinctiveness, it gave me a bit of the jargon, a little bit of the language. (Janet, Endocrinology)

Most participants highlighted a lack of shared understanding amongst their science colleagues of (the term) SoTL, suggesting that few of their colleagues saw such educational research as valuable, and that not many of its outcomes have infused science faculties. The potential for SoTL and DBER to inspire and influence teaching practice in science faculties remains relatively untested, but Liz (Acad. Dev.) felt that providing faculty with a language to describe their practice is powerful in itself, as she described: "…they live it and they breathe it and they feel it but they can't put a name to it."

Knowledge and Beliefs About Context (Grossman 1990)

The importance of an understanding of context in guiding practice was evidenced by the impact of the increasing diversity of students; participants saw it impacting on the range of preparedness of students and hence what could be undertaken and achieved in class. The majority of participants indicated that learning in one (science) domain is often dependent on skills gained in another (e.g. mathematics skills for chemistry), necessitating that time and curriculum space be spared to assist some or many students to upskill in these areas.

Participants' responses to part A of the interviews revealed that PCK components can be identified in the ways in which academics talk about their teaching practice, foreshadowing the potential authenticity of PCK as a useful concept in higher education. It is important to note that whilst about half of the participants had undertaken part (one unit/subject) or all of the Graduate Certificate in University Learning and Teaching (see Table 1), none of them had encountered any reference to PCK during their study.

Interview Part B: Resonance and Usefulness of the PCK Framework

Discussions undertaken during Part B of the interview, subsequent to the Magnusson et al. (1999) framework being shared with participants, indicated that PCK as a concept resonated strongly with participating science lecturers. All felt that all or most of it aligned well with their practice and ways of thinking about teaching and that they had come to think in accordance with the PCK construct in an ad hoc manner and without knowledge of the "jargon". Many felt comfortable that it accurately represented what they currently did. Liz (academic developer) had worked closely with science lecturers for many years through teaching in the Graduate Certificate in University Learning and Teaching, and she also validated the PCK framework:

> …a lot of this is resonating very strongly with what I see and hear from the science-based lecturers who come into the Grad Cert. Certainly their strength is in their knowledge of the content. They don't feel competent or strong or well versed in the pedagogy at all. They tend to operate in the way they were taught..... (Liz, Acad. Dev.)

Liz's statement concurs with the ways in which the academics spoke about their teaching practice during part A of the interview and in their responses to the PCK framework, indicating an imbalance in their expertise domains of teacher knowledge (Grossman 1990). Knowledge of their educational context was deemed by them to be strong, and they recognised that a focus on context is pivotal to effective teaching. Participants also felt that when teaching in their discipline area, their subject matter knowledge is exceptionally strong and they believed they know what their students need to know, understand and be like in order to graduate into a profession. However, whilst lecturers have expert knowledge of their discipline content, such understanding "…cannot simply be transferred to the student as a complete package…material has to be transformed and repackaged into a suitable format for delivery" (Kinchin and Hay 2007, p. 50). Hence, lecturers need to acquire pedagogical reasoning skill (Shulman 1987) and the ability to focus on their students and lead them "towards a more expert perspective" (Kinchin and Hay p. 54).

Several participants highlighted, however, that a key weakness was their pedagogical knowledge; they had either not been exposed to such understandings in any formal manner or if they had, it typically consisted of a brief overview of the area rather than any iterative and meaningful engagement with the literature or application of their understanding in a supported manner. Hence, although their content knowledge and knowledge of context were well developed, participants' pedagogical knowledge was much less so, potentially reducing their ability to develop their pedagogical content knowledge. Figure 5 represents this relative imbalance within the domains of teacher knowledge through the use of bolding (expertise) and lighter text (missing or reduced knowledge). As all agreed that both content knowledge and pedagogical knowledge are essential to good teaching, the impact of this imbalance on the development of PCK would benefit from investigation.

Importantly, a discussion of the Magnusson et al. (1999) framework enabled participants to acknowledge their strengths and weaknesses; as Mario explained whilst pointing to the PCK figure (Fig. 2):

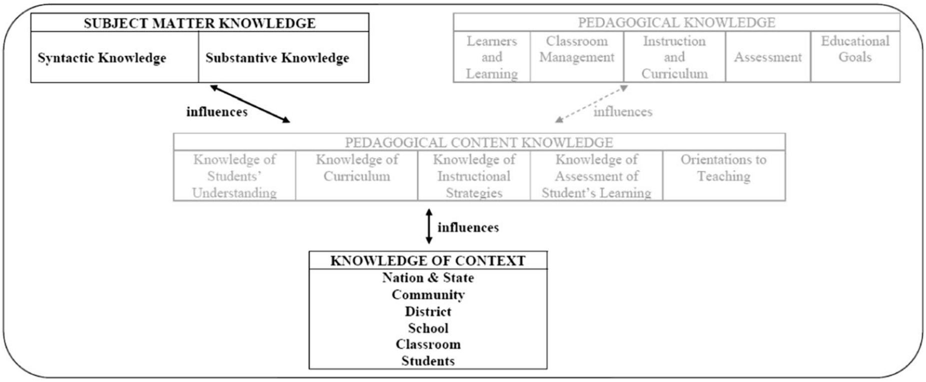

Fig. 5 Relative expertise in the domains of teacher knowledge (Grossman 1990) highlighted for higher education science lecturers

> I was happy with this bit [SMK]…So I needed this [PK], which is what I got from the Grad Cert and then the sorts of reading that it would point me at and so combining the two [PCK], is something which I think would drive me in all of my teaching now. (Mario, Microbiology)

Such commentary highlights the potential of PCK as a construct to influence the teaching activities of university staff, by giving them a way of reflecting on their teaching and recognising specific aspects that would benefit from revision or further professional learning. A key area in point was the absence of commentary from participants in relation to assessment, either the learning dimensions to be assessed or the manner in which such assessment should be constructed. Whilst assessment is clearly a component of PCK and incorporated into the pedagogical knowledge domains identified by Grossman (1990), it was not an area that research participants highlighted as deserving of attention. The PCK framework does enable, however, the initiation of conversations in this realm such that lecturers are stimulated to talk about their understandings of and approach to assessing student learning and scientific literacy.

Finally, although participants expressed strong support for the PCK construct, due to its strength in both representing what they do and in providing them with a framework with which to talk about their practice, all of them felt that it needed to be used carefully in the higher education context.

Using the Magnusson et al. (1999) PCK Construct With Scientists in Higher Education

The PCK construct could be introduced to lecturers as being useful for a multiplicity of purposes, but the manner in which it is presented and used should be chosen carefully. Liz (academic developer) felt that the detailed structure and pathways would be useful for scientists due to its use of "…discreet categories…and nice new pathways", but Janet felt a little confused by the way in which the PCK framework was represented diagrammatically (Fig. 2). This disparity in reception highlights the need for the construct to be presented in ways which acknowledge that each individual learns or receives information differently. Several participants expressed concern with the language used in the framework, for example, initially they misunderstood the use of the word "topics" (e.g. "knowledge for specific science topics") as they felt it did not truly represent the learning goals of science at university level.

For them, the word "topics" was strongly related to teaching content, and overwhelmingly participants agreed that learning science in higher education entails more than this. As Peter explained:

> …but it's not just the content, it's the way in which things are done. So it's a knowledge of techniques and processes and methods and so I guess it's not the culture of the discipline but it's sort of related to that…. (Peter, Physics)

Such concerns can be alleviated if the construct is explained carefully when first introduced to lecturers, and in this study, participants' unease dissipated as the interviewer unpacked the meaning of the term topics as the interview progressed.

As science lecturers respect research and inquiry-based practice, discourse around the T-R nexus is strongly influential and half the participants identified this way of thinking as being absent from the language of the framework and therefore a potential weakness if it was being used to engage science lecturers in discussion. It was also agreed that another way to engage academics, who do not necessarily spend a large amount of time thinking about teaching, is to highlight the research underpinnings of the framework—how it can contribute to the scholarship of the discipline and how it can assist them to improve their students' learning outcomes.

Considering participants' concerns about the PCK framework and aligning these with the aspects, noted as essential to good science teaching and learning in higher education, recommendations about how such a construct might be best introduced in this context emerged, specifically to:

1. Highlight science SoTL and incorporate it into the discussion of each PCK component.
   Engagement with SoTL and hence contributing to research outcomes through science DBER is viewed as a powerful way to motivate science lecturers to engage in teaching improvement initiatives. As such, participants felt it was essential to include SoTL as a key concept underpinning the framework.
2. Highlight the synergies with the T-R nexus literature
   Engaging with the PCK construct should enable science lecturers to consider three components of the T-R nexus (research-led, research-based and research-oriented) identified by Healey (2005b). Considering the T-R nexus when reflecting on both "the knowledge of science curricula" and "the knowledge of instructional strategies" components of the construct in particular, recognises its contribution to both the organisation of content and the organisation of learning opportunities that enable students to understand the nature of science, think like scientists and "do science".
3. Acknowledge the impact of student diversity
   As all participants identified the level of student diversity now present in their classrooms as being a pivotal factor in the design of their teaching, the way in which the PCK construct can assist them to address this contextual factor should be foregrounded. Enabling less-prepared students to achieve without "dumbing-down" the curriculum (Haggis 2006); continuing to challenge the "better" students without discouraging the "weaker" students; and catering for students enrolled in completely different courses (e.g. physics majors versus general science students) were seen as ongoing challenges. This aspect of their academic work was so compelling that participants agreed that it deserved focussed attention when engaging with the PCK framework.
4. Highlight the essential nature of both academic and social/relational aspects of learning
   Building relationships with students was identified as a requirement for learning science as by doing so, students are more likely to approach them (and their other tutors) early on when they are having difficulties or require clarification about some aspect of

their science learning. Several participants stressed that when engaging science lecturers with PCK, discussion should include the social and relational as well as the academic requirements for learning aspects of this endeavour.

5. Clarify the meaning of the language

   Clarifying questions were raised by participants throughout the interview as regards the meaning of several terms used in the PCK construct; terms that generally had established meaning for teachers from school settings. For example, the term "topics" (used in the framework in "knowledge of instructional strategies") was assumed by participants to mean "content" alone; hence, they felt that the meaning of language should be clarified as the PCK construct is discussed with lecturers.

6. Incorporate a discussion of familiar research

   Participants stressed that learning in science builds on foundational knowledge, and maintaining nonnormative understandings or missing key concepts limits the progress of students' learning. They felt that it is essential, therefore, that familiar and compelling literature relating to "alternative conceptions" and "threshold concepts" be acknowledged/referred to when PCK is presented.

Although each participant recognised the innate advantages of PCK as an organising framework, particularly so with the recommendations for its usage outlined here, they were quick to highlight that its usefulness more broadly within higher education might be limited.

University Lecturer Engagement with PCK

Participants identified four issues that they felt would impact on lecturer engagement with PCK which are not related to the efficacy of the construct per se:

1. There is little valuing/rewarding of scholarly teaching, education research and engagement more broadly in SOTL in universities and hence time spent engaging in these endeavours (inclusive of working with the PCK construct) may be viewed as time wasted.
2. There are not enough opportunities for lecturers to talk about learning and teaching and to share practice in appropriate and authentic situations.
3. Lecturers do not necessarily have the time or support to undertake the "risky business" of innovating learning and teaching.
4. Engaging with the enhancement of teaching is not undertaken in a systematic way; rather it is only considered when "something is broken".

These issues have been reported elsewhere, inclusive of varying suggestions for addressing them (Bush et al. 2011; Walczyk et al. 2007; Wieman et al. 2010), and their resolution is not the focus of this paper, but they do highlight potential barriers to the introduction of PCK into the narrative of teaching in higher education. Several participants provided suggestions, however, as regards how PCK could be utilised within the pre-existing climate for the purposes of engaging staff and improving practice, including:

- Provide alternative ways of presenting the framework (e.g. an interactive web-based resource) so that individuals are able to locate themselves within it via more than one point of entrance (e.g. questions needing answers, case studies, critical incidents).

- Work with already engaged university lecturers or “steersmen” (Middlehurst and Elton 1992), taking advantage of pre-existing interest, with the aim of gaining a critical mass of interest in PCK and influencing the system.
- Work with academics’ interests/drivers, for example, focussing on how PCK helps identify “what works”, thereby increasing learning efficiency.
- Work with learning and teaching managers (e.g. Associate Deans Learning and Teaching) to use PCK as a guiding construct to initiate action and benchmark practice.

Involving all science staff, however, was seen as an idle hope when research outcomes are privileged, and whole of department or faculty teaching improvement initiatives are scarce.

Taking PCK Further in Higher Education

The strong support from all participants for PCK in higher education highlights the importance of continued research in this domain. Several areas of research present themselves as a result of this study. Firstly, whilst academics have strong content knowledge in their field, the extent to which being “on top of the material” represents “specialised subject-matter knowledge” that is sufficient enough for them to effectively determine how “…the subject matter is selected, organised and formulated for the purpose of teaching and learning” (Deng 2007 p. 504) warrants further exploration. Equally, the impact of an imbalance of skills and understanding within the domains of teaching, and in particular academics’ extremely limited pedagogical understandings and/or a language of learning, on the development of a functional PCK deserves attention.

The effectiveness of engaging science lecturers in ways that have been found to be successful in the school sector also merits examination. One approach would be to explore the transferability of the work of Loughran et al. (2003) which enables school science teachers to document and reflect on their teaching goals and practice using the Content Representation Tool (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eRs). These resources, the authors argue (p. 222), also enable educators to work together to unpack expertise in science teaching through the lens of PCK, by sharing their knowledge about how to teach particular subject matter and to explore and analyse their subsequent practice. Engaging in ongoing and scholarly discussions about teaching and assessing science learning remain relatively rare in university science faculties, and when they do occur, there are few scholarly frameworks or resources to guide them. The CoRe tool and PaP-eRs might enable lecturers to work with the PCK construct in a way that is meaningful for them, as it involves them working on the substance of their teaching to make explicit what all too often remains tacit. In doing so, teachers’ conceptions of (beliefs about) teaching and learning would be unearthed, which is a necessary pre-requisite for them if they are to change their approaches to teaching.

Finally, there is great potential for collaborative work between science education researchers and science discipline experts, aimed at addressing the challenges academic scientists face in their teaching, PCK representing one construct to both generate and interrogate research and research data. Equally, by working together, they may be better able to encourage lecturers to explore school-based frameworks, exposing them to the value of pedagogical study and extending and building on the influence of existing frameworks such as constructive alignment, the T-R nexus, and conceptions about and approaches to teaching and engagement with SoTL. Such activities would also contribute to quality contributions to SoTL and hence may enhance its value in the eyes of science lecturers.

Conclusion

Science lecturers spoke freely about their approaches to and beliefs about teaching, with close reference to their practice. An analysis of their responses to interview questions highlighted an alignment between the way they talk about their beliefs, goals and practices and components of the Magnusson et al. (1999) PCK framework. The science lecturers viewed the PCK construct as a useful way of thinking about their teaching; they understood its intent, were able to make links between its five components and their practice, and could envision ways in which it might be used with colleagues in their schools (departments). Through an interrogation of this version of PCK, lecturers' conceptions of (beliefs about) teaching and learning were unearthed, providing the necessary first step in bringing about change to their approaches to teaching. PCK resonated well with science lecturers and was considered to be representative of their practice and ways of thinking about teaching. Whilst its usefulness was acknowledged by all participants, their combined responses indicated that the way it is presented to academics is important. Participants outlined what they perceived to be differences in teaching in the university context compared with school education, resulting in useful suggestions for utilising PCK in a higher education context. As a conceptual framework, PCK was perceived as useful by participating science lecturers and hence one that can influence teaching practice by providing them with a language with which to talk about their teaching and a construct which assists them to share ideas about teaching, plan their curriculum and teaching approach, and evaluate their effectiveness.

Appendix 1: Interview Schedule

Interview Schedule

Part A: Experience of Teaching Their Discipline

1. What science discipline would you say that you mostly align with?
2. What science subjects do you teach?

    a. Do they directly relate to your discipline area?
3. Do you and/or how long have you been teaching in your discipline at university level?
4. What is your experience of teaching in universities, for example, have you been a tutor as well as a lecturer, and have you been solely responsible for the development of your own units of study?
5. Can you describe for me your beliefs about teaching? For example,

    a. What do you aim to do in your teaching?
    b. Does your subject matter affect *your beliefs* about teaching or learning?
6. Can you describe for me your approach to teaching or how you teach, perhaps providing some examples for clarification?

7. Are there any particular conceptual frameworks that you have drawn upon to assist you in thinking about your curriculum development and teaching practice, or do you find any particularly influential as regards your pedagogical thinking and why?

Part B: The PCK Framework

8. To what extent and/or in what ways does the school-based science PCK framework resonate with you as a university science lecturer?
9. To what extent and/or in what ways do you think that the school-based science PCK framework might influence the teaching practice of university science lecturers?
10. Do you have any suggestions for how the framework might be enhanced to increase its relevance for university science lecturers?

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