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Secondary Physical Science Teachers' Conceptions of Science Teaching in a Context of Change

Dale L. Taylor[a] & Shirley Booth[b]

[a] Department of Physics, University of Cape Town, Cape Town, South Africa

[b] School of Education, University of the Witwatersrand, Johannesburg, South Africa

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Secondary Physical Science Teachers' Conceptions of Science Teaching in a Context of Change

Dale L. Taylor[a*] and Shirley Booth[b]
[a]*Department of Physics, University of Cape Town, Cape Town, South Africa;* [b]*School of Education, University of the Witwatersrand, Johannesburg, South Africa*

Pre-service teachers enter initial teacher education programmes with conceptions of teaching gleaned from their own schooling. These conceptions, which include teachers' beliefs, may be resistant to change, which is a challenge in contexts where teacher educators hope that teachers will teach in ways different from their own schooling. Conceptions of teaching found in different cultural and disciplinary contexts have contextual differences but have resonances with the results of research into teacher beliefs. Our sample of eight South African secondary physical science teachers was schooled in a system which encouraged knowledge transmission, but they were prepared in their initial teacher education for a learner-centred approach. After they had taught for a few years, we explored their conceptions of science teaching, using phenomenographic interviews. Four conceptions emerged inductively from the analysis: transferring science knowledge from mind to mind; transferring problematic science knowledge from mind to mind; creating space for learning science knowledge and creating space for learning problematic science knowledge. Internally these conceptions are constituted by three dimensions of variation: the nature of the science knowledge to be learnt, the role of the students and the role of the teacher. Media and practical work play different roles in the external horizon of these conceptions. These conceptions reflect the disciplinary context as well as the emphases of the sample's initial teacher education programme. This suggests that initial teacher education can significantly shape teachers' conceptions of teaching.

Keywords: *Teacher beliefs; Secondary school; conceptions of teaching; phenomenography*

Teachers' conceptions of teaching are significant because they underpin and inform their teaching approaches, which ultimately influence students' learning outcomes

*Corresponding author. Department of Physics, University of Cape Town, Private Bag X3, Rondebosch, 7701 Johannesburg, South Africa. Email: dl.taylor@uct.ac.za

(Kember, 1997; Prosser & Trigwell, 1999). Research demonstrates a correlation between science teachers' conceptions of teaching and their classroom practice (Koballa, Glynn, Upson, & Coleman, 2005; Lotter, Harwood, & Bonner, 2007). Thus, teacher education programmes might hope to imbue participants with particular conceptions of teaching, for example, student-centred conceptions. The problem is that pre-service science teachers' 12-year 'apprenticeship of observation' (Lortie, 1975) in schools means they enter initial teacher education programmes with beliefs about teaching which are resistant to change (Eick & Reed, 2002; Thomas & Pedersen, 2003). This is a challenge in contexts where it is hoped that teachers will teach in ways different from their own schooling, as happens wherever teacher educators promote the various innovative pedagogies which have emerged from science education research (see Millar, Leach, & Osborne, 2000).

South Africa presents one such context: a new secondary school curriculum was phased in over the period 2001–2008. This curriculum radically re-envisioned the role of teachers (Department of Education, 2000). However, curriculum implementation has been problematic, particularly in physical science, that is, physics and chemistry (Department of Education, 2009). Given the link between conceptions of teaching and student learning, and given physical science's status as a gateway to careers in science, technology and engineering, it is critical to understand how science teachers in such a context conceive their work. Of particular interest are teachers whose initial teacher education was in terms of the new curriculum but whose own schooling was under the old curriculum, since the marked differences between the old and new curricula make it possible to identify the influences of their initial teacher education. The aim of our study was to understand how science teachers schooled under a teacher-centred system but prepared in their initial teacher education for a learner-centred approach conceptualize their work. The specific objective was to explore the breadth of conceptions that science teachers from a particular initial teacher education programme have of their work, asking the question: what conceptions of science teaching are evident with these South African physical science teachers? We used a phenomenographic approach to explore variation in the conceptions across a sample of eight science teachers.

In this paper we review relevant research and explain our methodology. We then present the conceptions of science teaching uncovered in this study. We compare these to the conceptions revealed in other research and discuss what it is that marks these conceptions as being about science teaching specifically. We also consider the influence of the initial teacher education programme on the conceptions. Finally, we consider the limitations of the research and possible directions for further research.

Before starting, it is helpful to clarify what we mean by conceptions of teaching. Pajares (1992), in reviewing research into teacher beliefs, observed that 'conception' is a 'broader construct' (p. 320) which includes beliefs. For example, some see conceptions as comprising beliefs and intentions, where intentions are how teachers intend to teach (Norton, Richardson, Hartley, Newstead, & Mayes, 2005). Another relevant term is 'teaching orientations' which are seen as an overarching aspect of Pedagogical Content Knowledge, and which are described interchangeably as beliefs and conceptions (Friedrichsen, van Driel, & Abell, 2011). As our literature review will show, research into teacher beliefs yields results similar to those of research into teachers' conceptions of teaching, although the research is located in different research traditions with differences in approach: whereas conceptions usually emerge from the data, beliefs research tends to use existing typologies. Moreover, beliefs are generally seen as something a teacher 'has', whereas conceptions are usually viewed as constituted in a particular context, with a sensitivity to context. We note that conceptions are different from perceptions: perceptions are perceived directly through the senses, whereas conceptions require conceptualization and hence involve a level of abstraction (Bueno, 2013).

Research Review

Given the relationship between conceptions of teaching and teacher beliefs, we will review research into both, starting with conceptions. There are few studies which have specifically explored conceptions of science teaching, and so we locate these studies in the broader tradition of research into teachers' conceptions of teaching. Each study can be classified in regard to different contextual aspects: the level at which the teachers teach (university or secondary), the level of experience of the teachers (pre-service or experienced), the cultural context, the disciplinary context and, for secondary teachers, the curriculum context. We will show that although there are similarities across different contexts, contextual factors affect conceptions. However, the earlier studies ignored differences in disciplinary context.

Kember (1997) and Prosser and Trigwell (1999) report on a variety of mostly phenomenographic studies in the 1990s which looked at the conceptions of teaching of university lecturers in Australia, the UK and Hong Kong. The studies typically found a hierarchical outcome space, with a conception of conceptual change at the top of the hierarchy and information transmission at the bottom. Often the conceptions at the top of the hierarchy are characterized as student-centred, and those at the bottom as teacher-centred. Intermediate conceptions are sometimes characterized as 'transitional' (Kember, 1997), although this is disputed (Samuelowicz & Bain, 2001). Some researchers (Prosser & Trigwell, 1999) see the higher conceptions as including lower conceptions, but Kember (1997) rejects this view. A subsequent study extended this research to secondary teachers, finding the lowest order conception of Australian teachers to be similar to that of lecturers but a highest order conception of 'transformation of students' (Boulton-Lewis, Smith, McCrindle, Burnett, & Campbell, 2001).

The aforementioned studies showed the same conceptions across different disciplines, but subsequent research showed disciplinary differences in lecturers' conceptions of teaching (Lindblom-Ylänne, Trigwell, Nevgi, & Ashwin, 2006). Recent studies have looked at the conceptions of particular types of teaching, for example, biology (Subramaniam, 2013; Virtanen & Lindblom-Ylänne, 2010), geometry (Barrantes & Blanco, 2006), art (Lam & Kember, 2006), online (Gonzalez, 2009) and teaching using virtual learning environments (Lameras, Paraskakis, & Levy, 2008). Subject-specific nuances are evident in the conceptions, for example, German pre-service teachers' conceptions of teaching chemistry involve transfer, problem-solving and interaction (Koballa, Graber, Coleman, & Kemp, 2000). Two substantial studies of Chinese secondary science teachers found some conceptions derived from Chinese cultural emphases on examinations and behaviour with senior physics teachers (Gao & Watkins, 2002) and junior secondary science teachers (Yung, Zhu, Wong, Cheng, & Lo, 2013). Yung et al. specifically explored conceptions of *good* science teaching, similar to another Chinese study which looked at conceptions of 'excellent teaching' of middle school science and social science teachers (Chen, Brown, Hattie, & Millward, 2012), thus moving the focus from practice to the ideal, although one could argue that the conceptions uncovered in research always reflect teachers' ideals.

Whether they use phenomenography or not, all the aforementioned studies cite the original phenomenographic research and build on it. They show that teachers' conceptions of teaching are different from those of educational theorists, for example, transformation (Bernstein, 1996; Shulman, 1987) and didactical transposition (Brousseau, 1997; Chevallard, 1987). Most of the teachers' conceptions are about the purpose of teaching. One could critique that there is more to a teacher's experience of teaching than the purpose. This focus on purpose may be a consequence of phenomenography's assumption that there is a limited number of qualitatively different ways in which a sample experiences a phenomenon, which leads to a reductionist search for a small number of categories expressed by pithy statements.

However, studies outside this body of research yield similar categories. Research using metaphor has found conceptions such as 'transmitter' and 'facilitator' in Lebanon (BouJaoude, 2000), and 'teacher as knowledge provider' and 'teacher as facilitator/scaffolder' in Turkey (Saban, Kocbeker, & Saban, 2007). Brown and Lake (2006) used factor analysis to identify four conceptions of teaching in Australian and New Zealand teachers: transmission, apprenticeship-developmental, nurturing and social reform. Some Chinese and Turkish studies use the Teaching and Learning Conceptions Questionnaire (Chan & Elliott, 2004) which does not distinguish between conceptions of teaching and conceptions of learning, and identifies conceptions simply as either teacher-centred/traditional or student-centred/constructivist (Aypay, 2010; Cheng, Chan, Tang, & Cheng, 2009; Yilmaz & Sahin, 2011). A study which predates all the aforementioned found two conceptions of science teaching with Canadian pre-service teachers: knowledge transfer and changing understanding (Aguirre, Haggerty, & Linder, 1990). The resonances across all these studies suggest that the results of phenomenographic research into conceptions of teaching are not bounded by the research approach.

In regard to teacher beliefs, American research has yielded categories similar to the conceptions research. The Salish I project used the Teacher's Pedagogical Philosophy Interview to explore teachers' beliefs, and categorized them as teacher-centred, student-centred, conceptual or 'wobbling' between views (Simmons et al., 1999)—this last category is consistent with the phenomenographic view that a person may conceptualize a phenomenon differently in different contexts. The Teacher Beliefs

Interview (Luft & Roehrig, 2007) allocates respondents to one of five categories, ranging from teacher-centred 'traditional' to student-centred 'reform-based' with a transitional category in between, analogous to Kember's (1997) synthesis. Likewise, research into 'science teaching orientations' has revealed categories similar to the conceptions research. For example, one orientation is 'conceptual change' and others are classified as teacher-centred orientations (Friedrichsen et al., 2011).

Although teachers' beliefs tend to be resilient, they may change over time. Fletcher and Luft (2011) found that five science teachers moved towards learner-centred beliefs about teaching in an initial teacher education programme, but shifted back to teacher-centred beliefs during their first year of teaching. Similarly, Simmons et al. (1999) found that over their first three years of teaching, science teachers on average became less student-centred in their beliefs about teaching. These results suggest that context affects beliefs, similar to the way a conception is constituted in a particular context. However, research into conceptions has tended to measure conceptions at a particular point in time only, though a couple of recent studies have considered changes in conceptions of teaching of medical faculty (Calkins, Johnson, & Light, 2012) and of pre-service teachers (Swinkels, Koopman, & Beijaard, 2013). In South Africa, pre-service teachers' ideas have been researched, but there is a paucity of research on in-service South African teachers' thinking (Adler, Pournara, Taylor, Thorne, & Moletsane, 2009).

From all traditions, the research into conceptions/beliefs tends towards a simplistic binary of teacher-centred versus student-centred. In contrast Palmer (1997) posits that good teaching is centred neither on the teacher nor on the learner but on the subject matter. Evidence for this is seen in Wallace's (2005) analysis of good science teachers' accounts of their lessons, which shows that the science content of lessons is central to teachers' concerns. A focus on the subject matter *is* evident in many of the conceptions of teaching uncovered in research, but they have been classified as teacher-centred rather than subject-centred.

In summary, the research traditions converge in their results, finding similar categories for teachers' conceptions of teaching and teachers' beliefs. The conceptions research shows that conceptions of teaching are affected by contextual factors, in particular teaching level, disciplinary context and cultural context. In regard to teaching level, teaching conceptions have been researched more extensively at the university than at the secondary level. Most of the secondary level studies have worked with pre-service teachers rather than experienced teachers. In regard to disciplinary context, only a handful of studies have looked at science teachers' conceptions, and these have ranged from middle school to senior secondary teachers, with what counts as 'science' ranging from the breadth of the natural sciences at lower levels to physics at senior levels. A few studies have looked at conceptions of teaching a particular science, that is, chemistry or biology. In regard to cultural setting, the studies are spread across most continents but only one study has looked at the conceptions of African teachers, specifically Ethiopian lecturers (Zerihun, Beishuizen, & Van Os, 2011). No studies have looked at secondary African teachers of any subject. Our study thus extends this body of research.

Methodology

In order to explore teachers' conceptions of teaching, we chose not to use an existing tool, such as the 'Approaches to Teaching Inventory' (Prosser & Trigwell, 1999), since conceptions are sensitive to context and so a questionnaire validated elsewhere may use inappropriate wording and may fail to surface contextual nuances. Instead, we chose to use phenomenography, an approach which has been used to research teachers' conceptions across the world and which is sensitive to contextual differences, as our review of research shows. Phenomenography seeks to describe a population's conceptions of a particular phenomenon, in this case the phenomenon of teaching science. Phenomenographers explore the variation in conceptions in a population, which is appropriate since we wanted to explore the breadth in teachers' conceptions of science teaching. In this section we detail our population, sample and research instrument.

Population and Sample

The population of interest was secondary science teachers who had been prepared for a learner-centred approach in their four-year teaching qualification at the same university, but had been schooled in a transmission-oriented system. By secondary science teachers, we mean teachers who qualified with secondary physical science (comprising physics and chemistry) as their major teaching subject, and who were teaching physical science at the time of the study. This was a small population as only about six teachers graduated from this programme with physical science each year, and some were teaching mathematics or not teaching at all.

The sample for this research project comprised secondary teachers from this population who were willing and available to participate: four male and four female teachers with teaching experience ranging from about two to six years. Table 1 gives the details, using pseudonyms. The teachers were teaching physical science as their main subject, though some were also teaching or had taught a second subject. They taught in diverse schools and came from a variety of educational backgrounds themselves: rural (poorly resourced state schools in underdeveloped black rural areas), township (under-resourced state schools in black residential areas), intervention (private schools

Table 1. Sample

Teacher	Teaching experience (years)	Type of school	Own secondary schooling
Mr Xaba	1.9	Multicultural	Multicultural
Ms Grey	2.9	Multicultural	Private
Mr Mabasa	4.3	Township	Rural
Ms Ravele	4.7	Intervention	Rural
Mr Khuzeni	4.8	Township	Township
Mr Qwabe	4.9	Township	Township
Ms Cole	5.7	Private	Multicultural
Ms Zincume	6.4	Intervention	Township

which use donor funding to give good educational opportunities to students who would otherwise attend township schools), multicultural (well-resourced, well-functioning, formerly white state schools with considerable fees) and private (elite schools). The sample covered a wide range of variation in the population of interest, which was intended to maximize the range of conceptions uncovered.

Research Instrument

In phenomenography, data may be collected in any form that gives expression to conceptions, but most commonly it takes the form of interviews. We chose interviews over written responses because interviews generally produce richer data than questionnaires, in part because they allow for the immediate probing of answers. Moreover, teachers typically get few opportunities to talk in depth about their work and generally enjoy doing so, whereas written responses amount to more paperwork for teachers already burdened by administrative demands. The interviews were conducted by the first author in English, officially the language of teaching in the teachers' schools, and a language the sample communicated easily in, though the majority had an African mother tongue. An existing relationship facilitated the research since the teachers had been taught all or most of their physics and science teaching methodology by the first author. The interviews took place in the context of a larger research project into the practice and thinking of these teachers, in which the first author spent two days in each teacher's classroom (Taylor, 2013). The interviews were shoehorned into the spaces available in these two days, and were audio recorded.

The intention in a phenomenographic interview is to understand the interviewee's perspective of the phenomenon (in this case science teaching)—this is referred to as a 'second order' perspective (Marton, 1981). Thus, the teacher was first asked to briefly describe what happened in a lesson, even though the interviewer had been present in the classroom. Follow-up questions explored the teacher's purposes, or what the teacher thought students benefitted from the lesson. The data were grounded in actual teaching episodes because teachers' conceptions are often tacit, and thus difficult to access through generalizations such as 'what is your conception of teaching?' (Eley, 2006).

In phenomenography, the data collection is intended to cover the range of potential ways of conceptualizing the phenomenon. The intention is not to pinpoint features of the phenomenon (which could call for triangulation of the data) but rather to map structurally and referentially the ways in which the phenomenon is conceptualized. Thus, a phenomenographic interview approaches the phenomenon from different angles, until the phenomenon has been 'saturated', that is, the interviewer is reasonably sure of having apprehended the interviewee's conception of the phenomenon (Akerlind, 2005). This happened through discussion of multiple lessons, starting by asking the teacher to briefly describe the lesson, and then asking follow-up questions, for example why the teacher made particular choices in teaching. In addition, the teacher was asked 'Please tell me the story of what has made you the unique science teacher you are today', with follow-up prompts. The interviews were deliberately loosely structured and conversational in nature, allowing flexibility and ameliorating the power relations of the interview (Kvale, 2006). The average total time spent interviewing each teacher was 101 minutes.

Analysis

The first step in analysis was transcription of the interviews, which was done according to O'Connell and Kowal's (2005) standards of transcription which make for good readability while attempting to convey the intention of the speaker clearly. Transcription was done by a professional transcriber and checked by the first author. Language errors were not corrected. The transcripts were pooled for analysis. In phenomenography, individuals are not seen as 'having' particular conceptions: a particular person may express different conceptions of a phenomenon at different moments and in different contexts (Marton, 1981). Thus differences in individual contexts within the sample are ignored and the data are pooled in the analysis (Marton & Booth, 1997).

The analysis was largely the work of the first author, an experienced teacher educator, while the second author, an experienced phenomenographer in the area of science education, acted as a sounding board and critic throughout. A phenomenographic analysis is an iterative search for meaning in the data, seeking a limited number of qualitatively distinct categories of description (Akerlind, 2005). It is a grounded analysis of data, and so the conceptions emerged inductively from the data rather than being imposed deductively on the data (Richardson, 1999). Thus phenomenographers bracket their own perspectives (Ashworth & Lucas, 1998). Our existing knowledge of other 'conceptions of teaching' research was bracketed by asking 'what was the teacher's underlying intention?' for all instances in the data where the teachers talked about their teaching. These intentions were either implicit in what teachers focused on, or explicit: for example, one teacher said 'That's my mission, that's why I'm in a township school, I want them to see that […].' Out of this analysis, 56 intention codes emerged, over a total of 636 coded extracts. The most common intention codes were 'keep students interested or entertained' and 'get students to understand'. Each intention code was refined by revisiting all the data linked to that code, in the course of which some data were recoded. QSR nVivo 8 was used to manage the analysis of the data.

The next iteration in analysis involved looking for themes and sub-themes across the intentions. Two major themes emerged: intentions in selecting content knowledge and intentions in terms of what the teachers wanted students to do—such as 'get students to talk science' or 'get students to know definitions'. These concerns with content and with what students do suggest a view of science teaching as a mediation between science knowledge and students. There were, however, qualitatively different ways of viewing this mediation evident in the intentions. In addition, there was evidence of two distinctly different ways of viewing science knowledge: as problematic or not. This distinction appeared to be independent of grade or topic—for example, grade eight density was taken as problematic by one teacher, whereas nuclear power for grade nines was not seen as problematic by another. Out of the interplay of the themes, four tentative conceptions of teaching emerged. These conceptions were then tested on the original data.

In phenomenography, the conceptions are assumed to form an outcome space which represents the full range of variation of conceptions emerging from the data (Marton & Booth, 1997). The conceptions have some logical relationship to each other in the outcome space. Our experience is that the process of uncovering this structure is one of the strengths of phenomenography which distinguishes it from other grounded analysis (Strauss & Corbin, 1990), since seeing the conceptions in relation to each other brings new insights about the conceptions. By considering the ways in which the conceptions clustered in the data, the hierarchy of the conceptions became apparent.

For analytical purposes, phenomenographers break down conceptions into different aspects, most commonly the referential and structural aspects (Harris, 2011). The referential aspect is the meaning of the conception. The structural aspect of a conception is constituted by the internal and external horizons (Marton & Booth, 1997). The horizon is the boundary of the conception. The internal horizon is everything which is internal to the boundary, that is, the parts which constitute the conception and the relationships between the parts. The external horizon is that which is external to the boundary and is the backdrop against which the conception is perceived. The final step in our analysis was to identify the internal and external horizons of each conception. Here we revisited the original coding by intention, and interrogated the intersection of these codes with the coding of the data by each conception.

Results

Our research question asked for the conceptions of science teaching of South African physical science teachers whose teacher education prepared them for a curriculum significantly different from their own schooling. The answer is that there were four conceptions of science teaching evident, given in Table 2. The structure of the outcome space is a two-by-two matrix with the nature of the science knowledge on one axis and the nature of the mediation of that knowledge on the other. The conceptions on the right side encompass the corresponding conceptions on the left side, since not all science knowledge is problematic. The analysis revealed that conceptions on the bottom row of the table encompass the conceptions above. One salient distinction present in this outcome space is, on the one hand, the teacher seeing science knowledge as 'given' and 'unproblematic'—there to be handed to or taken by the students —and, on the other hand, 'problematic', conceptually difficult knowledge which requires significant conscious mental effort on the part of both teachers and students. A further distinction is between seeing the mediation of that knowledge as unproblematic and based on a transfer metaphor, or needing a metaphorical pedagogical space to be created for students to learn in.

The structural aspect of the outcome space is given in Table 3. The internal horizon has three constituent dimensions: science knowledge, the role of science students and the role of the science teacher. The specifics of these dimensions vary between the

Table 2. Outcome space: conceptions of science teaching

		Nature of science knowledge	
		Unproblematic	Problematic
Nature of mediation of science knowledge	Transfer	Transferring science knowledge from hand to hand	Transferring problematic science knowledge from mind to mind
	Create space	Creating space for learning science knowledge	Creating space for learning problematic science knowledge

different conceptions. The referential aspect of the conception arises from the interaction between the three dimensions. In this way the structural and referential aspects are co-constituted. For all the conceptions, media and practical work form part of the external horizon, but they have different roles in the different conceptions.

We next explore each of the four conceptions, explicating the dimensions of the internal and external horizons. In doing so, we use quotes from the transcripts, though no single quote captures a whole conception. We have indicated which

Table 3. Structural aspect of outcome space

		1. Transfer science knowledge hand to hand	2. Transfer problematic science knowledge mind to mind	3. Create space for learning science knowledge	4. Create space for learning problematic science knowledge
Internal horizon	Science knowledge	Given object for teacher to hand over	Problematic object for teacher to get across	Given object for students to access	Problematic object for students to make sense of
	Student role	Receive science knowledge	Understand science knowledge	Explore, ask questions, and play	Construct science knowledge
	Teacher role	Hand over science knowledge	Grapple with science knowledge, then get it across	Create a space for exploration	Create a space, facilitate
External horizon	Role of media	Source of science knowledge for students	Source of science knowledge for teacher and students which needs mediation	Provide space for exploration; give ideas to teachers	Open up space, but need mediation
	Role of practical work	Give science knowledge	Elucidate science knowledge	Provide space for exploration; provoke questions	Open up space; teach investigation skills

teacher gave each quote in order to give some idea of the distribution of the quotes over the sample, although in the analysis the data were pooled.

Transferring Science Knowledge from Hand to Hand

In the first conception, science knowledge is seen as a given object, often contained in definitions. When asked what his students got out of a particular lesson, a teacher replied: 'I think they came away with the definition—lots of definitions actually' (Khuzeni). The teacher's role is to hand over this knowledge, for example 'all the extra stuff in terms of notes I've given either over the overhead [projector] or dictated' (Xaba). Students may prefer the teacher to 'just give them notes at the same time [as teaching them]' (Khuzeni). The 'just' giving of notes implies that the science knowledge can be adequately handed on in this way. The students' role is to receive the knowledge, often by listening: 'So I say to them, I'm not re-teaching anything you should have been listening to in the first place' (Grey). The need to say things only once implies a transferral of knowledge from the teacher to the student as long as the student is listening.

Media is a source of knowledge which can be accessed unproblematically by students because 'if they can read, then they can remember it' (Zincume). The Internet is another such source: 'There's cartoons that are there, explaining the whole double slit experiment on YouTube and how matter could have diffraction patterns, how you get those fringes. It just explains the whole topic in just a couple of minutes' (Qwabe). Because the knowledge is unproblematic, a 'couple of minutes' of explanation is adequate for explaining 'the whole topic'. There is a sense in which such an explanation is one-size-fits-all. The role of practical work is to give science knowledge to students, for example with ticker timers 'you can explain a whole lot of concepts from velocity to acceleration to displacement' (Mabasa).

Transferring Problematic Science Knowledge from Mind to Mind

In the second conception, science knowledge is a problematic object: 'The content I find it very heavy. It's difficult for me to cross it to the learners' (Ravele). The teacher's role is to get the message across to learners:

> They don't understand the concept of the mole, they can recite a definition, but when you ask them to explain what one mole is, they battle. And I struggle to also get it across, because I seem to battle a little bit to go down to the level in terms of trying to explain it. (Grey)

This quote shows that knowledge is not contained in definitions and that explanations are not one-size-fits-all but need to be tailored to the audience, which can be a challenge, as a teacher explained: 'I never really know how far to explain things, like what's more beneficial for them. Because I think sometimes if we over-explain, it actually gets too much for them' (Cole). The knowledge is not easily communicated by notes: 'I tried to make the notes more hands-on and explain a little bit more. Instead of just throwing down information and expecting them to understand'

(Grey). This shows that the role of the students is to understand the knowledge, and the aforementioned 'mole' quote shows that students should be able to express their understanding by explaining. The problematic nature of the science knowledge means that the teacher has to grapple with it before the lesson:

> I had to develop that element of wanting to make sure that whatever that I say, it's actually right, it's correct in the sense, and that my presentation of lessons should be such that I've already sat down and then thought about it. (Mabasa)

Whereas in the first conception, science knowledge may only pass through the teacher's hands in the form of notes, in this conception, science knowledge always passes through the teacher's mind.

Media, including university textbooks, multiple school textbooks and the Internet, play a central role in the teacher's initial grappling with the knowledge to be taught, thus getting it 'into her head': 'I use probably about four or five textbooks and then I take the information I feel is relevant' (Grey). Textbooks are also a source of knowledge for students, but need to be mediated 'Because I find that the textbooks, number one, they battle to study from it, and I think that they get very overwhelmed with the amount of writing that they see straight away' (Grey). This mediation may involve elaboration: 'the way that the textbook does it is very brief, […]. So I just add a little bit extra' (Grey). The role of practical work is to help elucidate problematic knowledge; for example, a demonstration 'made them to understand a little bit of what I mean when I say diffraction' (Ravele).

Creating Space for Learning Science Knowledge

In the third conception, the teacher's role is to create a space where students can encounter science knowledge. This can be through a science museum visit: 'we went to the SciBono Centre, and it was lovely, they were exploring, they were experimenting, doing all these fun things' (Zincume). One teacher created a museum-type situation in his classroom:

> All your stuff, your science equipment: don't put them in a storeroom and hide them. Put them visible where they'll see them every day. So they may ask 'What is this?' and you'll tell them 'I'll tell you when we get to that point' or 'Come break time [recess], I'll show you what it does.' Don't explain what it does, just show them what it does and then that's it. They will ask a question 'Why does it does this?' and then there is a lesson that you've just done. (Qwabe)

These quotes show that, having set up the space, the teacher relinquishes control over learning, often allowing some play: 'I really, really was so happy to see the learners trying stuff themselves. Trying to play around with—and they were so concentrated, very focused on that particular [thing]' (Mabasa). This play leads to learning: 'once they start playing with the kit, I don't know what happens in them but they get to understand those things better' (Zincume). The aforementioned quotes show that the students' role is to explore, ask questions and play, and the role of practical work is to open up the space for this.

Media can also be used to open up a space. One teacher got his students to use the considerable collection of textbooks and other reference books in his classroom to find useful information: 'they can read, but it's important that they must select the information that they need. And that is what I'm really trying to get across: what information do you need?' (Qwabe). These examples imply that students will be able to get the science knowledge from the practical work or books—the knowledge is taken as unproblematic. Media may also provide a teacher with ideas: 'I got this idea from, I was reading on the Internet, de Bono's hats encourages discussion' (Qwabe).

Creating Space for Learning Problematic Science Knowledge

A teacher can also create space for learning problematic science knowledge, which is the view of the last conception. A teacher commented about a unit she had taught on density which involved lots of hands-on work with apparatus:

> And I think, even if they don't quite understand what they're doing, I think it gives them enough first-hand experience. You know, it's just sowing seeds so that—it's a complicated concept, very abstract, so I think even just sowing those thought processes, a seed, I think it will eventually help. (Cole)

In this space, seeds of problematic knowledge may be sown. After setting up the space, the teacher relinquishes control over learning, leaving the space open for different students to learn differently:

> I try to keep the classroom as open as I can to allow them to figure out a method for themselves. So I throw them into the deep end a lot. But I want them to be able to think for themselves and to come up with a way of doing it that makes sense to them rather than following a method I put on the board. (Grey)

The students' role is to 'think for themselves' and construct their own knowledge. The space is characterized by learners engaging with the teacher and each other, often disagreeing:

> they'll literally get into arguments with each other. They will literally get into a screaming match sometimes, but I just leave them because they're actually—they'll bring someone in from the back of the class to answer a question and they work very well together. (Grey)

This conversation often leads to learning:

> So if you talk about something to someone else, you might learn better, or that person can easily pick up your misconceptions or your problems or the wrong answers that you give.[…] I encourage them to talk about their answers. And if you've still noticed that I keep on walking around, they keep on arguing, that 'this person is saying 'this is the answer' and I think that's the answer'. And then I must come and 'but why do you think this is the answer, why do you think that's the answer?' (Qwabe)

This last quote shows that the teacher continues to play a role after setting up the space, in this case facilitating discussion by asking further questions.

Practical work may be used to open up a space, providing experiences which initiate students' construction of knowledge (e.g. the density unit described earlier), as may texts, in this case YouTube videos:

> I first got a bunch of videos from YouTube especially on solar flares and how the earth's magnetic field disperses them. And I used that as an introduction. And the kids found that totally fascinating. And then they started asking questions themselves about how it works and that sort of thing. And then once they were asking those questions, we could get into the real concepts, as opposed to me saying 'these are the concepts, they're important, learn them'. (Cole)

However texts may again need some mediation, though the mediation may well take the form of questions rather than explanation, for example:

> Are you able to look at the diagram that you see in your book and interpret whatever you see live? And if that is the problem, why is it a problem? What do we need to do in order for you to actually see that this is more or less the same but it's presented in a different way? (Xaba)

The role of practical work is also to teach investigation skills 'and get a sense of what it means to do prac work, what it means to get certain results' (Xaba).

Discussion

How do these conceptions compare with the results of other phenomenographic research into conceptions of teaching? And how do they reflect the disciplinary and initial teacher education contexts of the research? We answer these questions in this section.

Comparison with Other Phenomenographic Research

Table 4 gives a comparison between this study and some of the other phenomenographic studies to which we referred earlier. We have put what we see as comparable conceptions in the same horizontal position, but this fit is better with some conceptions than with others. In particular, the conceptions of teaching as 'creating space for learning' do not map well onto other conceptions. The extreme teacher-centred conceptions in Table 4 did not surface in our study—all the conceptions in our study involve students in some way. Overall, the conceptions of our study fit best with the 'top' end of lecturers' conceptions, rather than with other studies of secondary teachers. However, the matrix structure of our outcome space (Table 2) is substantially different from other studies' simple hierarchies.

We next relate the dimensions of the internal horizon to the dimensions found in other research. Although Kember (1997) included internal dimensions in his synthesis of 13 studies, not all subsequent research has done so. The studies which do identify between four and nine different dimensions (Gao & Watkins, 2002; Gonzalez, 2009; Lam & Kember, 2006; Lameras et al., 2008; Samuelowicz & Bain, 2001). Most of these give the roles of the teacher and students as dimensions, similar to our finding. However, only Samuelowicz and Bain (2001) and Kember's (1997) synthesis

Table 4. Comparison of conceptions of teaching research results

South African secondary science teachers This study	Lecturers Prosser and Trigwell (1999)	Australian secondary teachers Boulton-Lewis et al. (2001)	Chinese secondary science teachers Gao and Watkins (2002)	
		Transformation of students	Conduct guidance	Student-centred
			Attitude promotion	
Creating space for learning problematic science knowledge	Helping students change conceptions	Facilitation of understanding in students as learners		
Creating space for learning science knowledge	Helping students develop conceptions	Development of skills/understanding	Ability development	
Transferring problematic science knowledge from mind to mind	Helping students acquire teacher knowledge			
Transferring science knowledge from hand to hand	Helping students acquire conceptions of the syllabus			
			Examination preparation	Teacher-centred
	Transmitting the teacher's knowledge	Transmission of content/skills	Knowledge delivery	
	Transmitting the concepts of the syllabus			

include knowledge as a dimension, and both consider only the *construction* of the knowledge, for example whether it is constructed by students or possessed by the lecturer. Both these studies and three others include 'content' as a dimension, but by this they mean who or what determines the selection of content, rather than the nature of the content. Since teacher, students and knowledge are the three dimensions of the classical didactic triangle, it is surprising that the nature of the knowledge has not come to the fore in previous studies.

There are three dimensions found in three or four of the other studies but not ours: interaction, intended learning outcomes and teaching methods. Interaction did not emerge as a dimension of variation in this study because all the teachers used and valued interactive approaches, and, since phenomenography looks for variation, similarities tend to be washed out of the analysis. We regard intended learning outcomes as conceptions of learning rather than a dimension of conceptions of teaching. Some teaching methods, namely the use of practical work and media, featured in our study as part of the external horizon rather than the internal horizon.

No other studies consider the external horizon of conceptions of teaching, whereas we found the use of practical work and media to be part of the external horizon. However, Gonzalez (2009) includes resources as a different internal dimension and, as noted, some other studies include teaching methods as part of the internal horizon, though the examples given do not specifically include the use of science equipment or media. In summary, while the conceptions in our study have resonances with those of other studies, our analysis brought to light dimensions which have not previously emerged in research into teachers' conceptions of teaching.

Disciplinary Aspects of the Conceptions

In comparing our sample's conceptions to other phenomenographic research, we have not limited our discussion to conceptions of science teaching. Indeed, one possible criticism of our study is that the conceptions which emerged in this study are conceptions of teaching generally and not specifically conceptions of *science* teaching—the word 'science' could be replaced with any disciplinary body of knowledge. We dispute this: the central place of practical work in the external horizon reflects the disciplinary context. Moreover, the understanding of science knowledge as 'problematic' and the view of science teaching as 'creating a space' reflect the disciplinary context, as we will explain.

Physics is notoriously difficult because of the way a lot of physics principles contradict common sense derived from life experience. Similarly, chemistry is difficult because it explains observations by means of abstract models reflected in a particular language of symbols and representations. Of course there is difficult content in any discipline, but it is no coincidence that the research into alternative conceptions has been more extensive in the physical sciences than in any other field of education research (Meyer & Land, 2006).

Problematic knowledge is similar to the idea of 'troublesome knowledge' coined by Perkins (1999) which can be defined as '"alien", or counterintuitive or even intellectually absurd at face value' (Meyer & Land, 2006, p. 4). 'Threshold concepts' needed to access the powerful ways of thinking in a discipline often involve troublesome knowledge (Meyer & Land, 2006). Brousseau (1997) assumed that student difficulties in learning echo Bachelard's 'epistemological obstacles' which hampered the historical development of science. The notion of problematic knowledge is similar to that of troublesome knowledge and epistemological obstacles. However, we have not used these terms because we do not want to imply that the sample was referring to gatekeeping threshold concepts or historical epistemological obstacles.

The space created for learning is metaphorical, but it happens in a physical space which shapes the learning space—a physical space which has science equipment and books in it, and which is literally a space in which students move. The teacher shapes both the physical space and the metaphorical space—she shapes the physical space by arranging equipment and books strategically, and the metaphorical space by occasioning students' engagement with both the physical resources and science knowledge. Even if it is not a formal laboratory, a science classroom looks different from other classrooms because of the existence of science apparatus. We suspect that the physical space of science teaching has informed the conceptions which see teaching as creating a space for learning, and hence these conceptions reflect the disciplinary context in which the research was conducted.

Influence of Initial Teacher Education

In the introduction we noted the challenge which initial teacher education programmes face. Our sample was schooled under a curriculum which encouraged knowledge delivery, but their university education prepared them for a curriculum where the teacher is viewed as having seven roles. One of these roles is 'discipline specialist' and another is 'learning mediator' who constructs 'learning environments' (Department of Education, 2000). These roles are reflected in the conceptions in this study. All four conceptions are about mediating disciplinary knowledge, with the complexity of that knowledge recognized in two of the conceptions. The conceptions of creating space for learning are about constructing learning environments. The teacher-centred knowledge delivery conception of the old curriculum was not evident in our study, in contrast to other studies with secondary teachers (Table 4). It appears that these teachers have embraced the conceptions of teaching offered in their university education, despite their own secondary school experiences and despite mostly being located in schools where implementation of the new curriculum has been problematic. This suggests that initial teacher education can indeed shape teachers' conceptions, and that this influence lasts some years after teachers have completed their initial teacher education.

Limitations and Directions for Further Research

We noted in our literature review that phenomenography's research outcomes are shaped by its assumption that there are a limited number of ways of experiencing a phenomenon. Moreover, phenomenographers look for variation. That our study found a small number of conceptions of teaching which focus on the purpose of teaching and that there is variation in these conceptions may be a function of our methodological choices. However, we note the similarities in results from across different research traditions evident in our literature review. Thus we contend that the teachers' perspectives of their work which have emerged here offer useful insights which transcend the boundaries of phenomenography.

Our study has provided only a snapshot—we do not know what the teachers' conceptions were at the start or end of their teaching degree, how their conceptions have developed since they finished their degree or how they will develop in the future. A longitudinal study would provide further valuable information on teacher learning.

The population from which our sample came is a small population of South African science teachers who qualified recently from a particular institution. We do not claim that our sample is representative of all South African science teachers. However, in our literature review we noted the similarities in conceptions/beliefs about teaching which have emerged across different continents, and thus feel that our research, localized though it may be, has a contribution to make to the global picture of understanding the conceptions/beliefs which shape teachers' practice. Research into teachers' conceptions in different South African initial teacher education programmes and globally in other contexts would develop this further. This could lead to an inventory for using with secondary teachers, different from the one developed for university lecturers (Prosser & Trigwell, 1999). Given that teachers' conceptions of teaching are key to student learning, this is an important area for further research.

Conclusion

We set out to find the conceptions of science teaching held by eight secondary science teachers. We found four qualitatively distinct conceptions (Table 2), the most comprehensive of which is creating space for learning problematic science knowledge. This conception reflects the disciplinary context by acknowledging the conceptual difficulty of science knowledge, and by reflecting the specialized space in which science is often taught. All of the conceptions see practical work as an important part of the external horizon, which also reflects the disciplinary context. The conceptions are consistent with the four-year initial teacher education programme in which these teachers participated. Thus, it seems that initial teacher education can have a profound long-term effect on beginning teachers' conceptions of teaching, even where these conceptions differ substantially from the dominant conceptions under which teachers were themselves schooled.

In the larger study in which this study was located, the science content of lessons, and hence the overall quality of lessons, tended to be better where the related interview data evidenced conceptions which view science knowledge as problematic (Taylor, 2013). This suggests that conceptions of science teaching which recognize science knowledge as problematic may correlate with better student learning. We think that the notion of teaching as creating a space for learning is appropriate where knowledge is understood to be problematic and hence learning not straightforward, since the space metaphor suggests that different students can take different journeys through the space. Thus, in addition to efforts to create learning mediators, teacher educators might do well to help pre-service teachers understand that they hold varying conceptions of teaching and that within the physical sciences there exists problematic knowledge which is not simply received by students but rather apprehended through engagement in appropriately designed learning spaces. There may also be value in getting in-service teachers to reflect on their conceptions of teaching, with the hope of developing those conceptions and so improving classroom practice.

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ORCID

Dale L. Taylor http://orcid.org/0000-0002-5888-8431
Shirley Booth http://orcid.org/0000-0003-2315-1197

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