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Views About Learning Physics Held by Physics Teachers with Differing Approaches to Teaching Physics

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Abstract Research into teacher thinking offers potential insights into ways of promoting better teaching. A recent qualitative study explored the views about physics, and learning and teaching physics of a group of teachers whose classroom practice was 'traditional' and a group who used conceptual change teaching approaches. This paper focuses on the views about learning physics held by the two groups. To summarize and compare the groups, a composite description was created for each group. This composite description represents all the common views of teachers who were in that group. The composite description is termed 'typical' teacher. The study concluded that the conceptual change teachers' views about learning physics were constructivist while the traditional teachers held absorptionist views.

Keywords Physics teachers · Views about learning physics · Views about teaching physics · Teaching approach · Pedagogy

Introduction

The apparent decline in student interest in science and the science disciplines is a concern in many countries and has been linked to traditional teaching practices that are underpinned by a teacher centred, transmissive pedagogy (Lyons 2006). In the case of physics, the traditional approach to teaching involves a focus on facts, definitions and formulas (Linder 1992; Osborne 1990; Wildy and Wallace 1995),

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and the apparent assumption that understanding is developed through laboratory work and by completing numerical problems (Osborne 1990). This kind of teaching implies to learners that physics concerns discovered and observable truths about the world, and that mathematical representations of the truths are both clear and precise (Linder 1992). However, there is now considerable research suggesting that this type of teaching approach often fails to promote student understanding of physics ideas (Duit 2009). In the light of such research, developing a qualitative understanding using conceptual change approaches (e.g., Scott et al. 1991) before introducing formulas and mathematical work is now considered to be more appropriate as “for many students [equations] are difficult and may obscure the ideas rather than clarify them” (American Association for the Advancement of Science 1993, section F, para 2). Thus, using mathematics to represent physics ideas should be seen as an endpoint in physics teaching rather than the starting point that is traditionally the case (Mulhall and Gunstone 2008).

Yet traditional teaching approaches persist (e.g., Tytler 2007), and while instigating change in physics teaching is a complex issue (Van Driel et al. 2001; Wallace and Louden 2003), there is a recognition that such change needs to take into account the beliefs that teachers hold which influence their teaching, including beliefs about physics, and learning and teaching physics (Calderhead 1996). For example, the majority of physics teachers are products of traditional teaching approaches, and may have developed beliefs that are consistent with the kinds of implicit messages about physics and learning physics described above. In addition, physics teachers may believe that traditional teaching practices are appropriate because they faithfully conform with the principles of the physics discipline (Tobin et al. 1997; Tobin and McRobbie 1996). Given the mathematical nature of physics knowledge, the claim by de Souza Barros and Elia (1998, Table 1) that physics teachers prioritise the “manipulation of mathematical symbols” supports these assertions.

This study sought to better understand why physics teaching is as it is, and to help those who work in physics teacher education programs. The research was part of a larger qualitative study which explored the views about physics and learning and teaching physics amongst a group of teachers whose teaching approaches were traditional and compared these with the views of a group of teachers who used conceptual change teaching approaches (Mulhall 2005). In this paper, we focus on the views about learning physics held by the two groups of teachers, who all taught upper secondary school physics. We discuss the theoretical perspectives that framed the study, and the relevant literature concerning research on teachers’ views in general and on physics teachers’ views in particular. We then explain the research context, the aims of the study and method used, and summarize the results. Finally we discuss implications of the findings.

Theoretical Perspectives

It is now widely recognized that traditional teaching approaches in science and the science disciplines often fail to promote student understanding of science concepts, and that the conceptual understandings of even successful science students may be at odds with scientists' views (Duit 2009). The literature on students' alternative conceptions and a view of learning as a process of conceptual change has informed a number of research programs that have explored ways of improving students' understanding of science ideas (Gunstone 2000). As a consequence of such research, improvement in students' science understanding is still fundamentally seen in terms of changing their alternative conceptions, but the process is now recognized as being more complex than the term 'conceptual change' suggests. Although the term is still used, it is now recognized that 'concept addition' is more appropriate because learners often acquire a number of different explanations for a phenomena and learn to judge which is appropriate in a given context, such as the science classroom (Fensham et al. 1994).

A number of approaches to teaching for conceptual change have been developed and generally involve student collaboration and discussion (Miyake 2008). Common to these approaches is a constructivist view of learning which, basically, is that "people construct their own meanings for experiences and anything told them" (Fensham et al. 1994, p. 5), the consequence being that individuals may construct different meanings for the same event.

Taken at face value, a constructivist account of learning seems to propose a paradox to science teachers—if students construct their own understanding, how can teaching achieve the aim that students acquire particular understandings of physical phenomena that are in accord with the scientific view? Indeed the consequence of a constructivist view of learning may be (mis-) interpreted by some to mean that 'anything goes', that teaching should be concerned with helping students to develop their own understandings regardless of their consistency with the correct scientific viewpoint (Matthews 1992), an interpretation rejected by a number of 'constructivist' academics (Gunstone 2000; Scott and Driver 1998).

The constructivist perspective of learning developed by Driver et al. (1994) provides a valuable framework for teaching science knowledge that helps resolve the apparent paradox described above. Their key to the problem of understanding how science knowledge can be taught in the classroom links ideas about students' construction of meanings with the nature of scientific knowledge itself. Briefly, Driver et al. argue scientific knowledge is "socially constructed and validated" (p. 6) by the scientific community using ideas and practices that individuals are unlikely to develop or discover alone. From this perspective, the science 'way of knowing' is quite different to the everyday 'way of knowing' that students are familiar with, and learning science is akin to being "initiated" into the ideas that science has constructed and its practices (p. 6), including what have been called "the rules of the game" (Carr et al. 1994). Thus, the teachers' role is to introduce science ideas and to help learners make sense of them (Driver et al. 1994).

The implication for teaching physics is that students need to be introduced to the physics 'way of knowing'. Student talk is seen as playing a key role in promoting understanding, so teachers need to provide opportunities for students to discuss their own and physics ideas about phenomena (Leach and Scott 2002; Scott and Driver 1998). Whereas in traditional classrooms definitions and formulas are presented early, and understanding is assumed to develop when these are used to solve problems (Linder 1992), the social constructivist position is that problem solving should be introduced *after* understanding has been developed.

Research on Teachers' Views

A wide range of terms has been used in the literature on research concerned with teachers' views or beliefs (Pajares 1992). Nevertheless, in his major review on research in this area, Pajares notes there is general agreement amongst educational researchers that (1) people develop beliefs that are self-perpetuating from a young age; (2) each person develops a belief system that helps him/her to make sense of the world; (3) knowledge and beliefs are "inextricably intertwined" (p. 325), with beliefs tending to color the way information and events are construed; (4) beliefs are an important determinant of behavior, including thinking, and of the ways individuals organize new knowledge; and (5) for research purposes, the beliefs of individuals necessarily "must be inferred" (p. 315).

Consistent with this latter conclusion, Kagan's (1990) review of approaches to studying teacher cognition noted the difficulty of researching teachers' views as teachers may have difficulty expressing, and even recognizing, their beliefs. For this reason, extended interviews are considered to be highly appropriate for exploring teachers' views (Kagan 1990). Such interviews provided the main data source for this study of physics teachers' views.

Teachers' Views about Learning Science

Both this and the next section have a primary focus on research into teachers' views about learning science or physics respectively. As will be shown, researchers have often linked such views with views about the nature of science/physics and of teaching science/physics.

The overall picture painted by researchers of traditional teaching practices in both science and the science disciplines is one in which knowledge of facts and processes is valued over intellectual engagement with ideas. Such an approach is linked to an absorptionist view of learning and a discovery view of the development of scientific knowledge (Linder 1992; Prawat 1989, 1992; Tobin 1998; Tsai 2002, 2006). Allied to these views is a common emphasis on the stereo-typical 'scientific method' that is used to portray the objectivity of science knowledge (Gallagher 1991). Typically the teaching focus is on presenting science content to be learned rather than developing understanding (Benson 1989; Duschl and Wright 1989; Linder 1992). Studies have found that pre-service teachers in science and science disciplines also tend to think of teaching and learning in their subject area in terms of presenting facts for learners to absorb (Aguirre et al. 1990; Hewson et al. 1999).

Few studies have included teachers with constructivist beliefs, probably because they tend to be part of the minority (Tsai 2002). Tsai's study of 37 teachers found 59 % held traditional views about learning science while only 14 % held constructivist views about learning science. He also explored the consistency of teachers' beliefs about learning science, teaching science and the nature of science and found that (a) for some 60 % these beliefs were congruent, and (b) where only two sets of beliefs were beliefs were congruent, these were most likely to be beliefs about learning and teaching science (pp. 777–778). Hashweh (1996) compared a group of teachers with empiricist views about learning or knowledge with a group that had constructivist beliefs about learning or knowledge and found the latter had a greater awareness of student alternative conceptions and of teaching strategies likely to promote student understanding.

Studies of teachers' beliefs often make inferences about teachers' practice but lack observational data to support these inferences (Hashweh 1996; Tsai 2002). A study by Tsai (2007) of 4 teachers that included classroom observations found consistency between their beliefs about learning and teaching science, their epistemological beliefs and their practice. Kang (2008)'s exploration of pre-service secondary teachers' 'personal epistemologies' and teaching goals also included observations of teaching but found considerable discrepancies between their beliefs and practice due to issues arising from learning to teach rather than their beliefs per se.

Finally, Tobin and McRobbie (1996) propose that cultural "myths" about teaching are responsible for the persistence of traditional teaching practices. These myths include "[t]he transmission myth" in which the teacher is seen as the main supplier of knowledge to students (leading to emphasis on memorisation of facts and algorithms, and on the teacher's power over students); "the myth of efficiency" (leading to coverage of the content being considered to be more important than promoting student understanding); the myth that a certain "rigor" must be maintained in teaching (leading to the teacher being seen as the guardian of disciplinary standards) and the myth that "teachers should prepare students for success in examinations" (leading to an emphasis on students learning facts and algorithms in order to answer examination-type questions correctly) (pp. 229–237).

Physics Teachers' Views about Learning Physics

Linder (1992) argues that traditional physics teaching represents "scientific activity as an on-going collection of mind-independent facts about objective reality" (p. 111). He contends that such "metaphysical realism overtones" are manifested in physics teaching and lead to poor student learning (p. 111), supporting his argument with examples of physics graduates' explanations of sound given in clinical interviews. He suggests physics teachers' "epistemological commitments" (p. 120) may be linked to the following aspects of physics teaching: the encouragement of students' rote learning of physics facts (p. 112); the "widely held" belief that conceptual understanding is associated with the ability to solve stereotypical physics problems (p. 114); "a rapid rate of instruction" in order to protect "some set of unwritten standards" (p. 117); and, discouragement of student reflection on their understanding, and an associated belief that learning is building up a collection of pieces of knowledge (pp. 117–118).

Several of these claims and inferences about physics teachers' beliefs have much in common with the cultural myths suggested by Tobin and McRobbie (1996) above and are consistent with another study in which a beginning physics teacher who expressed constructivist views of learning nevertheless emphasized numerical problem solving rather than conceptual understanding in his teaching (Tobin et al. 1997). Indeed, a study of undergraduate physics teaching highlighted the challenging nature of changing one's teaching practices without a concurrent deep-seated change in one's learning beliefs (Volkmann et al. 2005).

The Context of the Research

The study explored the views of two small groups of secondary school physics teachers: those whose teaching approaches were consistent with conceptual change practices (hereafter referred to as 'the Conceptual teachers') and those whose teaching approaches were best described as 'traditional' (hereafter called 'the Traditional teachers'). The teaching characteristics of these two groups are elaborated later but the essential difference was that the former used approaches that focused on developing students' conceptual understanding and made considerable use of student talk about their ideas concerning the physics of a situation, whereas the approaches used by the latter presupposed student understanding of concepts based on the logic within the content (Flores et al. 2000). These teachers all taught a physics course for students in the final two years of schooling (i.e., Year 11 and 12) in schools located in an urban region of the Australian state of Victoria; this course involved high stakes examinations in the second year.

Both groups contained five teachers. The Conceptual teachers were part of a group of ten volunteer teachers who participated in a separate three year funded research project, the Understanding Physics Project (UPP) which explored the learning outcomes of teaching that focused on developing student conceptual understanding in a Year 11 unit of work in which the content areas were motion and DC electricity (Gunstone et al., in preparation). All UPP participants were interviewed about their views about physics and learning and teaching physics. Later, these views were explored amongst the Traditional teachers who were invited to participate in this study, partly on the basis of convenience and partly because we had grounds for supposing that their teaching practices were traditional, an assumption later verified as outlined below.

There was some overlap of the two groups in terms of views about physics (Mulhall and Gunstone 2008). The Traditional teachers saw physics as discovered, close approximations of reality. Among the Conceptual teachers, views about physics ranged from a social constructivist perspective to more realist views. However, as a group, the Conceptual teachers tended to have more complex views about physics than the Traditional teachers. As noted earlier, in this paper we focus on the views about learning physics in these two groups of teachers.

Research Questions

The questions guiding the research were as follows.

For each group of physics teachers:

(1) What are the perceptions of how students learn physics?
(2) What are the perceptions of the difficulty of understanding physics concepts?
(3) What are the views of what understanding in physics entails?

and

(4) How do the views of the two groups compare?

The Research Approach

The research was qualitative and employed a case study methodology (Eisenhardt 2002). Semi-structured interviews were used to explore the views about physics, and learning and teaching physics of all teachers. Classroom observations were used to determine each teacher's membership of the Conceptual group, the Traditional group, or neither group (see below). These observations also provided a means of checking there were no inconsistencies between each teacher's classroom practices and interview responses.

The criteria for classifying a teacher's practice, shown in Table 1, were developed by the UPP research team of four highly experienced physics education researchers (all former high school physics teachers), including both authors. The use of questions in the classroom played a central role in this classification: Conceptual teachers were those who were observed to use questions to promote student engagement with physics ideas, rather than just giving answers or information whereas Traditional teachers focused on seeking correct answers from students or providing these themselves. It should be noted that if observations of a teacher's classroom practice did not clearly suggest that a teacher belonged in either of the two groups, he/she was not included in the study.

The Conceptual teachers were observed at least twice during UPP as they taught Year 11 physics lessons ranging from 45 to 90 min. The observers were either of two research assistants, one of whom was the first author, who took written notes in situ to describe what the teacher and students did and said during the lesson, and later generated a teaching profile to describe how the teacher concerned supported,

Table 1 Classification of teachers according to observations of practice

	Conceptual teacher	Traditional teacher
Teaching focus	Getting students to reveal their ideas about the physics in a particular situation	Getting students to solve problems
	Getting students to discuss and reason about which of a range of explanations for a situation is best	Getting students to perform cookbook style laboratory work
	Developing conceptual understanding	Developing explanations using algorithms
The role of questions	To promote student engagement with physics ideas	To provide correct physics information

or did not support, student understanding. These profiles were used by the UPP research team to classify the teachers. As a consequence of this classification process, five (5) of the ten UPP teachers were considered to be ‘Conceptual’.

The Traditional teachers were similarly observed twice by the first author during Year 11 physics lessons lasting between 45 and 90 min. Again, teaching profiles were prepared to determine whether or not each teacher belonged to the Traditional group; this decision was made by the two authors, both members of the original UPP research team. All those in the original group of five (5) Traditional teachers continued to be classified as ‘Traditional’.

The Conceptual group comprised three females (Caitlin, Dorothy, and Heather) who taught at private girls schools and two males (Charles and Robert) who taught at government and private co-educational schools respectively. All the Traditional group were males (a not unusual situation, given the generally male profile of Australian physics teachers), and comprised Ross and Ryan, who taught in private co-educational schools; Joe and Pat, who taught in academic boys schools; and Chad, who taught at a government co-educational school. (All names are pseudonyms.) As is typical in Australian schools, all teachers taught a range of levels (from Year 7 to 12) and subjects (including mathematics and general science) in addition to Year 11 (and often Year 12) physics.

The semi-structured interviews were complex and wide-ranging in design, and included questions about the interviewee’s perceptions of the nature of physics and its relationship to mathematics; of how physics knowledge was originally generated; differences between teaching physics and other subjects; content areas of physics that were difficult to teach; valued teaching strategies; and about learning physics. The interview also explored the interviewee’s conceptual understanding through their responses to a set of quotes containing some common student misconceptions. Examples of interview questions are provided in Appendix 1.

Each interview took between 45 and 90 min and was audio-taped. Two were fully transcribed. After examining these transcriptions, it was decided that detailed summaries containing all important quotes would suffice for the remaining interviews, so this was the approach used. Each summary/transcription was prepared by the research assistant who conducted the interview.

The analysis for this study involved multiple readings of the data and discussions between both authors. The first author developed the initial analysis, which the second author checked for agreement or disagreement in the data, and differences were discussed until consensus was reach. Two forms of analysis were employed, each with a different purpose.

Within case analysis involving the development of extended narrative descriptions was first conducted to understand the detail and nature of each individual teacher’s views. This was followed by a cross-case search for patterns to understand the similarities and differences of teachers’ views within a group and between groups (Eisenhardt 2002). This paper focuses on the results of this second form of analysis, which was used to generate a list of the most commonly held views for each group (where ‘most commonly held’ views refers to views held by at least 4 teachers). From each group’s list of most commonly held views, a composite description that we termed a ‘typical’ group member was constructed to enable identification of beliefs that best characterized the group. In a sense, the composite description (the 'typical' teacher) for each of the Conceptual and Traditional groups was obtained by overlaying the views of all the teachers within those respective groups and identifying where there was most overlap. We note that the description of the 'typical' Conceptual/Traditional teacher is not a description of an actual teacher and nor are the descriptions intended to be a form of generalization across the wider physics teacher community.

A number of steps were taken to ensure validity and reliability. These included annotations of summaries/transcripts to capture an interviewee's apparent confidence or lack of confidence in answering questions; interview questions that concerned issues related to the aims of the physics course being taught by the teachers; the practice of having the second researcher check for discrepancies in the initial analysis to counter potential researcher bias; and maintenance of an audit trail. Furthermore, data for each of the first three research questions was provided by more than one interview question, thus enabling corroboration of interpretations. In addition, while the classroom observations were not used to provide information about teachers' views, they were not inconsistent with the interview data.

Overview of the Interview Data

A section of the list of the most common views about learning physics of the teachers in the Conceptual group is provided in Appendix 2 as an example of this form of data. It should be noted that where an idea, belief or insight is shown in bulleted point form, the original list contained more than one variant on this idea. As discussed above, the lists of the most common views of the Traditional and Conceptual groups were used to construct the respective views of a 'typical' teacher within each group. We emphasize that the 'typical' Conceptual/Teacher is a device to allow identification and discussion of beliefs that *characterize* the *group* of Conceptual/Traditional teachers who participated *in this study*. The typical Traditional teacher is referred to as 'he' because all members in this group were male. The views of the typical teacher are described below in the present tense to give a sense of immediacy to the discussion.

The Views of the Typical Conceptual Teacher

The typical Conceptual teacher considers that physics is a hard subject, not so much because it is mathematical but because its ideas are difficult to understand. He/she believes students can obtain correct answers to numerical problems without having much understanding about the underlying physics ideas. To develop students' conceptual understanding, the typical Conceptual teacher highly values teaching procedures where the focus is on students' intellectual engagement with physics concepts rather than on their ability to use formulas and manipulate numbers. However, he/she holds the view that students construct their own understanding, that therefore teachers cannot mandate students' learning, and that, nevertheless, teachers can (and should) try to influence the nature of students' constructed understanding.

The typical Conceptual teacher believes that students often come to physics with views formed from their own everyday experiences that may be in conflict with physics ideas; and that mechanics is particularly hard for learners for this reason. He/she considers such ideas need to be challenged in order that students' understanding may develop. He/she highly values student discussion for promoting understanding, as talking about one's ideas can help clarify one's thinking and one may learn by listening to the ideas of others.

At times the typical Conceptual teacher reflects on his/her own learning and understanding in physics and draws on this when trying to make sense of how students learn. The typical Conceptual teacher's views that physics models always have limitations, that understanding physics is difficult and that learners construct their knowledge, suggest that he/she sees physics ideas as being problematic in terms of the extent to which they represent reality, and considers the development of understanding of those ideas as tricky. Importantly, he/she considers the process of developing understanding includes learners' recognition that physics ideas (e.g., formulas, laws, models) are always limited representations of reality.

The typical Conceptual teacher considers that doing 'problems' helps students' learning in physics. Given that the word 'problem' in physics teaching is a generic expression that includes both qualitative and quantitative exercises, does this mean that the Conceptual teacher regards both types as equally useful? Firstly, the Conceptual teacher considers he/she should focus on developing conceptual understanding using qualitative exercises before introducing students to formulas. Secondly, he/she believes that students can do quantitative problems without understanding. Hence it is likely that he/she sees qualitative problems as being more valuable than quantitative ones in terms of promoting student conceptual understanding. How, and whether, the Conceptual teacher thinks quantitative problems help learning per se is not clear, but it is likely that he/she recognizes that practice at solving them is important preparation for Year 12 examinations, where most questions require a response based on a formula (McKittrick, personal communication, 2002a, b).

The Views of the Typical Traditional Teacher

The typical Traditional teacher considers physics is mathematical and abstract. According to him, physics is hard to understand, although some areas are easier than others. The Traditional teacher considers that students' success in physics depends on their ability, interest and how hard they work.

The typical Traditional teacher thinks that students learn physics by:

- doing 'problems', which develops students' ability to answer examination type questions and consolidates their learning. While, as noted above, 'problems' may be either quantitative or qualitative, the typical Traditional teacher values and emphasizes the former, in keeping with his views that physics is mathematical.

- doing laboratory work, and that this learning comes from the experience itself; that is, the experience alone teaches students. This is consistent with the Traditional teacher's view that physics ideas are revealed through observation and experiments.
- the teacher revealing physics ideas through telling, explaining, and demonstrating. This is consistent with the Traditional teacher's view that physics knowledge is unproblematic.

The Traditional teacher also considers that learning physics provides information that is useful in everyday life.

Discussion

The views of the typical Conceptual and Traditional teachers, described above, facilitate comparison of the views of the Conceptual and Traditional *groups*, the focus of our fourth research question. We compare these views using the framework provided by our first three research questions, and give examples from individual teachers.

What are the Perceptions of How Students Learn Physics?

The typical Conceptual teacher believed learning involves cognitive activity by the learner and that individuals construct their understanding. As two teachers from the Conceptual group noted:

> C[1]: [Students have] got to be in charge of the learning themselves … they've got to construct the knowledge (CI1 2(a)(i))[2] (Charles)
> C: [T]hey've got a lot of [pre-existing ideas] themselves, whether they're right or wrong, and you've got to build on that rather than just … pour new things in on top of [those ideas]. (CI2 2(a)) (Caitlin)

The typical Conceptual teacher also recognized the social influences on learning. He/she considered that students need opportunities to engage intellectually with, and discuss, physics ideas in order to challenge and develop their understanding:

> C: [I tell my students to always ask,] "Why are we doing this… and what am I meant to be learning?" …. [Don't] get drowned in the detail but … look for the big themes. …. You can work out the detail once you've learned the big themes. So … engage in discussions and … really … be active …. (CI1 10(a)) (Robert)
> C: So to truly study physics [students] need to interact in the classroom.… Explaining to other students is good. I maintain that the best learning I've ever done with physics has been when I've taught it—that's when I've truly understood it …. (CI2 7(a)) (Heather)

[1] C and T denote a Conceptual and Traditional teacher respectively.

[2] This is an interview code.

C: [If] you want them thinking, it's got to be challenging. Learning takes place most powerfully when you don't know what's going on, [when] suddenly [you realize] something's not quite right. …. You follow the logic of something through that's wrong, and suddenly you are confronted with "If that's true, then this other bit's not true", and that's a very strong way of learning. (CI2 5(a)) (Charles)

On the other hand, the typical Traditional teacher conceived of learning physics in terms of acquiring information (e.g., through doing laboratory work and reading the textbook/notes) and developing one's skills at answering examination type questions (e.g., through doing problems):

T: How [students] actually obtain that ownership of the knowledge in maths [i.e., mathematics] is by doing the exercises and, ah, trying the problems themselves. In physics it's a mixture of doing the exercises, which are theoretical questions et cetera, but also doing the experimental side themselves. (TI 10) (Joe)

T: Um, the best students read through their pracs [i.e., laboratory tasks] before they come into class, they read … their textbook ahead of where we are at the moment so they know what's coming up. Um, they add to any notes that they get in class by, ah, referral to textbooks, … and they do … problems that apply the principles that they've learned to various situations as much as they possibly can. Once they've done all that then they start looking at exam papers, and how to apply the principles and laws and equations and so on to the various scenarios the examiners come up with. (TI 17(a)) (Ryan)

Thus for the typical Traditional teacher, learning was the result of doing 'work' (e.g., problems, laboratory work), as illustrated by the response of two Traditional teachers when asked what advice they would give to a student on how to learn physics:

T: Work hard. …. That means cover whatever material you're supposed to cover. Um, if concepts appear difficult, go and ask. Don't sit there and say, "Well I've put [in] all the effort that I can," um, [but] go and ask for an explanation. (TI 17(a))) (Ross)

T: I've always found the harder I worked, the smarter I got. So … it's just a matter of you [being] prepared to think about things, … and read the book rather than just glazing over [it] … and if you have questions you've got to come and ask …. (TI 17(a)) (Joe)

Implicit in the above and following comments is the view that how well one learns depends on how much work one does and whether one has the appropriate abilities/skills:

T: [T]he kids that don't want to learn, they're hard to teach, and you probably don't teach them much at all; and the kids that want to learn, they virtually teach themselves. (Laughing.) So I'm just there waving a piece of chalk around! (TI 13(a)) (Chad)

While the typical Conceptual teacher would not disagree that effort and ability are involved in learning, his/her view of learning also encompassed the view that understanding of physics concepts is not automatically developed through the 'work' recommended by the typical Traditional teacher but is promoted through collaborative tasks and discussion with peers.

Unusually for a Traditional teacher, Pat considered discussion between students helps their learning, but his reasons differed from those of the typical Conceptual teacher: he appeared to think that the main benefit of discussion was that it helps to develop students' ability to correctly use physics terminology.

> T: How to learn [physics]? Talk physics as much as you can. …. [Students have] got to take the risk and talk to their friends, talk to their teachers. When they're in class, [they should] try as often as they can to use the physics language and terminology, to develop confidence in expressing their understanding in physics. If you do that then you'll find doing the calculations with formulas a lot easier. (TI 17(a)) (Pat)

Dorothy was the exception among the Conceptual teachers in that her views of learning physics were only implicitly constructivist, and she did not seem to engage in much metacognitive thinking; nevertheless, she did see learning in more complex terms than the typical Traditional teacher. For example, when asked why she valued interpretive discussion in her teaching, she replied,

> Because it's far more useful to dredge … information and understanding out of [students'] own heads than get it from me. It can be valuable to get it from a teacher and in the end sometimes they have to, but … if … they've got the knowledge, but they just haven't pieced it together, it's really nice to see them piece it together. You can see on their faces that suddenly [they've realized], "Oh, hold on, I hadn't thought of that, but what about this …." Often it's so exciting, you can almost see it go, "Boyng!" and they go, "Oh, yeah…!" And that's good and they feed off each other. (CI2 5(a)) (Dorothy)

What are the Perceptions of the Difficulty of Understanding Physics Concepts?

The typical Conceptual teacher considered that physics ideas are often counter-intuitive and inherently difficult to understand. The typical Traditional teacher thought students find physics difficult because it is mathematical and abstract, and thus requires certain attributes, which many students do not have, to learn physics successfully. The following quotes illustrate some of these different perspectives:

> C: Yeah, I don't think [physics is] an easy subject to grasp. I think the students' idea of hard is different to what I think of is hard. … I [think] … the concepts are still difficult to grasp but students … see … the amount of work and numbers of problems they get correct as the hard bit rather than grasping ideas …. (CI3a 1(b)) (Heather)
>
> C: It's not the students [i.e., that make teaching physics difficult]—it's the concepts themselves. Mechanics is counter-intuitive at times and electricity is just (laughing) weird. (CI2 6(b)) (Charles)
>
> T: If you haven't got reasonable mathematics then you're always going to struggle with physics. (TI 3(b)) (Joe)

> T: [Many] students … don't have the abstract, ah, conceptual ability to, um, take a situation and … and analyze it. …. [C]onsequently they find it difficult. (TI 2(a)) (Ryan)

The typical Conceptual teacher saw the ideas of physics as more demanding in terms of learning than did the typical Traditional teacher. The latter (T) thought that, in principle, physics ideas could be transferred intact to the learner; by contrast, the former (C) thought that, in principle, this was unlikely because learners interpret these ideas according to their own pre-existing (and often, non-scientific) frameworks.

> T: [Chalk and talk is] probably the easiest … or best way of giving that information to them quickly. They seem to want it that way and respond to it from me better that way, ah. (TI 15(b)) (Chad)
>
> T: You can use … that power of mathematics, um, in school in simple ways to show students things like, um, you should expect there to be a rule for conservation of energy because you can derive an energy conservation equation from the one of the motion equations. $2as = v^2 - u^2$ gives you the equation: work done = change in kinetic energy. (TI 3(b)) (Pat)
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> C: [Y]ou've got to build from where they're at and often they are at quite different spots and completely different from where you might think they might be …. (CI2 2(a)) (Caitlin)
>
> C: [The most challenging area to teach is] the forces part of [the unit on] motion. It's just so different from what they come in with. Half the time you are breaking misconceptions …. It's like [students say], "You put your foot on the accelerator [of a car] to keep a constant speed"—and you do, and they know that—and that's what they've lived with all their lives … but [the teacher says], "No, that's not what happens." (CI2 6(a)) (Dorothy)

As noted earlier, there was some variation among the Conceptual teachers in the extent to which they viewed physics knowledge as constructed, and the ideas of physics as problematic in terms of representing reality. However, all Conceptual teachers seemed to agree that *learning* about these ideas is challenging and acknowledged the active role of the learner in developing his/her understanding. The typical Traditional teacher, on the other hand, saw these ideas as difficult because not all students have the necessary abilities to understand them. The typical Conceptual teacher appeared to be more sensitive to students' misconceptions than the typical Traditional teacher, a finding similar to Hashweh (1996, p. 61).

What are the Views of What Understanding in Physics Entails?

The typical Conceptual teacher considered that developing understanding takes time, and involves challenging students' existing ideas and engaging them in thinking about and discussing their ideas with each other. Importantly, the typical Conceptual teacher considered that students can be successful 'traditional' problem solvers without having much understanding of the underlying physics ideas.

C: I much prefer reading [test] answers where kids have made little numerical mistakes but they've understood the basic concept … than reading answers where, OK, they got most of the numerical stuff happening but you ask a curly question that actually makes them think and nothing's there. They just haven't understood it. (CI2 4(a)) (Robert)
C: [You should start] with a question and develop an answer that really means something to you and not just an answer that is correct … to get an answer that you can justify. (CI1 10(a)) (Heather)

It is interesting that our construction of the typical Traditional teacher's views about understanding is necessarily highly inferential because understanding was not something he talked about much. With his view, noted above, that learning concerned the acquisition of information, it is possible that the typical Traditional teacher saw 'understanding' as 'knowing that'. Indeed an important distinction between the typical Traditional and Conceptual teachers is that the former (T) thought of learning, partly at least, as coming to know that particular physics ideas are close approximations (or actual descriptions) of reality while the latter (C) considered an important part of learning physics is learners' recognition that physics ideas are always limited in the extent to which they represent reality.

T: Some of the ideas [about light and matter] are a bit confronting. But when [students] realize that *it's reality*—that we have electron microscopes, for example, that are based on this, this, um, set of ideas, then they accept it …. (TI 16(b), our emphasis) (Pat)
C: [At the conclusion of teaching about gravity, I say,] "Just one little question: we know gravity so well now, who's going to tell me what gravity is? Have you noticed that we've dodged that?" (CI3a 6) (Charles)

Joe, a Traditional teacher, also had this latter view, although this seemed to be because of experimental error/shortcomings rather than because he saw physics ideas as constructions, which was the view of the typical Conceptual teacher:

[W]e give them a formula then we say, "Now treat this with a degree of respect" [as] the reality is not matched by the formula in most cases…. if you wanted to match a formula up with reality [then] we have to bend the reality so much that that becomes no longer a real situation, so they're a starting point to understanding. You know, they're important … the problem is [if] you start believing in them as an absolute truth, then you're bound to come a cropper [i.e., to completely fail].
Interviewer: What do you mean by 'as an absolute truth'?
Well, let's take the simple things like the, ah, equations of straight line motion, … $v = u + at$ and … if we go out and do an experiment … we'll find in most cases it doesn't quite fit …. [W]e look at how close things are and we draw approximate straight lines and, ah, the reality is that, um, things don't [actually] behave like particles in billiard ball physics. … And then you refine that model and … eventually you come to a better model, but there's always some variation in reality to what you think is the theory. (TI 3(a)) (Joe)

Conclusions and Implications

In this qualitative study, the views about learning physics of physics teachers who used conceptual change teaching approaches were compared with the views of teachers who used traditional approaches to teaching physics. Both groups contained 5 teachers who taught Year 11 physics in a two year course that had high stakes examinations in the second year.

The study suggests the two groups of teachers had distinct views about learning physics:

- The Traditional teachers thought of physics learning as the outcome of doing certain activities, and in terms of acquisition of information about physics ideas. For the Traditional teachers, physics was seen as hard because it is mathematical and abstract, and many learners do not have the special attributes necessary to learn it. It was as if the Traditional teacher did not distinguish between knowing a piece of physics information and understanding it.
- The Conceptual teachers thought that learning involves cognitive activity by the learner, and that individuals construct their own understanding in terms of their personal frameworks. For the Conceptual teachers, the ideas of physics were considered to be counter-intuitive and troublesome in terms of learning. They saw discussion as being important for learners as it helps tease out and develop understandings of physics ideas.

This study has interesting implications for the preparation of physics teachers. The mathematical nature of physics is one that sets it apart from other sciences, particularly those studied at school. As we have argued elsewhere, this tends to convey a precision and certainty to the ideas of physics, and may act to reinforce traditional teaching approaches (Mulhall and Gunstone 2008). Indeed some research suggests that beginning student physics teachers can be more disposed towards traditional teaching practices than student teachers of other science disciplines (Markic and Eilks 2008). Furthermore, although 'teaching for understanding' through the use of conceptual change teaching approaches is now considered desirable in each of the sciences (e.g., Mintzes et al. 1998), it is a goal that some find hard to implement (Uzuntiryaki et al. 2010; Wallace and Louden 2003), particularly in teaching contexts where students sit examinations developed and administered by an external authority (Geelan et al. 2004). Nevertheless, we argue conceptual change practices should continue to be promoted in teacher education, given research now highlights the benefits to student learning of conceptual change teaching in physics in high stakes contexts (Gunstone and Mulhall 2009; Gunstone et al., in preparation). Such findings are consistent with our claim that the views about learning physics of the Conceptual teachers in this study were more empowering than those of the Traditional teachers. That is, the Conceptual teachers' views about learning physics enabled them to be more strategic in their planning through sensitizing them to a greater range of pedagogical opportunities (Pierce and Stacey 2010) afforded in the physics classroom. Faced with a student who did not understand, the Traditional teacher's essential response was to tell the student to 'work harder' while the Conceptual teacher acted as a diagnostician and designed activities that responded to the student's difficulties.

We conclude by considering ways of helping pre-service physics teachers think about physics and learning physics so they develop more effective teaching approaches, and at the same time acknowledge change may take time (Gustafson and Rowell 1995).

All the practicing teachers in this study acknowledged that physics is difficult for learners; by contrast, a related investigation of 13 pre-service teachers' views found they all believed physics to be easy to learn (Mulhall 2005). Thus, an essential task of physics teacher preparation programs is to encourage pre-service teachers' reflection on their beliefs, to promote their awareness that physics is not easy for many learners, and, importantly, to promote their appreciation that learners' difficulties are often related to both the substantive nature of physics concepts and how learning occurs. One approach to fostering such reflection is to examine the extraordinarily large body of research about the widespread nature and persistence of students' alternative conceptions in physics for both school students (that is, the students the pre-service teachers will teach) and for undergraduates and practicing teachers (that is, the pre-service teachers themselves). Such a focus on the physics understandings of learners they will teach, and on their own understandings, will also focus on the issue of what it means to understand an idea. This may also then be effective for helping some pre-service teachers to understand the problematic nature of many physics concepts. This is particularly so if unpacked from the perspective that learners construct their own understandings based on their experiences and existing personal frameworks *and* that the ideas of physics are constructions that have been developed through a process of negotiation by the physics community using frameworks that are quite different to those of students. Encouraging pre-service physics teachers to think about how they might change their practice to accommodate these issues of both learning and the nature of physics is also important. Linking experience of, and reflection on, practice and beliefs recognizes their intertwined nature and synergistic relationship (Veal 2004), and is fundamental to the long term goal of developing practice that is at the heart of pre-service teacher education.

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Appendix 1

Examples of Interview Questions

1 A friend's daughter/son is choosing their subjects for VCE [i.e., Years 11 &12]. Your friend is uncertain about what subjects their child should do and asks you "What **is** physics?" What would you say?

3 (a) Many people have seen the formula

$$E = mc^2 (show\, formula\, on\, a\, card).$$

In your opinion, how accurately does a formula like this portray what physics is?

4 How is physics knowledge produced?

10 You are a teacher. But why a teacher of physics?
(Important issues to attempt to follow here:
–Why teach physics rather than mathematics/other science? How do you see physics and mathematics/other sciences as differing?)

11 What do you consider to be your role as a teacher of Year 11 physics?

15 (a) What sort of teaching strategies do you value using most with your physics class? Why?

16 (a) What areas of physics are the most challenging for you to teach? Why?
(b) What areas of physics are the most challenging for students to learn? Why?

17 (a) If a Year 11 physics student asked you for advice on how to learn physics, what would you tell them?
(b) Do you think this is what the average Year 11 student does?

18 I want to show you a number of things I've heard students say during physics classes I've been in either as a teacher or as an observer over the past 20 years. I'd like you to comment on each one, particularly in terms of the understanding of physics the student/students seem to have. *(Show cards with each of the comments below.)*

> (d) In a class discussion a Year 11 student said,
> "According to Newton's third law of motion, two teams having a tug of war must always pull equally hard on one another. If this were true, it would be impossible for either team to win."

Appendix 2

See Table 2.

Table 2 Examples of common aspects of conceptual teachers' views about learning physics

Views about learning physics	Teacher code[a]
You can answer physics numerical questions without much understanding	Cn, Cs, Dy, Hr, Rt
Students need to think/engage the mind in physics	Cn, Cs, Dy, Hr, Rt
Developing understanding of physics ideas is intellectually challenging	Cs, Dy, Hr, Rt
Working out the physics in a situation is intellectually challenging and involves logical deduction	Cs, Dy, Hr, Rt
Interviewee sees either biology or chemistry or both as more factual (in terms of learning) than physics	Cn, Cs, Hr, Rt
Students initially feel threatened when challenged to work out and express their ideas about the physics of a situation	Cn, Cs, Dy, Hr

Table 2 continued

Views about learning physics	Teacher code[a]
Content areas which are more challenging for students	
■ Motion	Cn, Cs, Dy, Rt
Students learn physics by	
■ Doing problems—helps consolidate learning	Cn, Cs, Dy, Hr
■ Student discussion of physics ideas	Cn, Cs, Dy, Hr, Rt
■ Trying to link various physics ideas	Cn, Cs, Dy, Rt

[a] The Conceptual teachers' names were coded Cn, Cs, Dy, Hr, Rt respectively

References

Aguirre, J. M., Haggerty, S. M., & Linder, C. J. (1990). Student-teachers' conceptions of science, teaching and learning: A case study in preservice science education. *International Journal of Science Education, 12*(4), 381–390.

American Association for the Advancement of Science. (1993). *Chapter 4: The physical setting*. Benchmarks online. Retrieved 8 July 2010, from http://www.project2061.org/publications/bsl/online/ch4/ch4.htm#F.

Benson, G. D. (1989). Epistemology and science curriculum. *Journal of Curriculum Studies, 21*(4), 329–344.

Calderhead, J. (1996). Teachers: Beliefs and knowledge. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 709–725). New York: Macmillan.

Carr, M., Barker, M., Bell, B., Biddulph, F., Jones, A., Kirkwood, V., et al. (1994). The constructivist paradigm and some implications for science content and pedagogy. In P. J. Fensham, R. F. Gunstone, & R. T. White (Eds.), *The content of science: A constructivist approach to its teaching and learning* (pp. 147–160). London: The Falmer Press.

de Souza Barros, S., & Elia, M. F. (1998). Physics teachers' attitudes: How do they affect the reality of the classroom and models for change? In A. Tiberghien, E. L. Jossem & J. Barojas (Eds.), *Connecting research in physics education with teacher education*: Published by International Commission on Physics Education. Retrieved 19 August 1998, from http://www.physics.ohio-state.edu/~jossem/ICPE/TOC.html.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5–12.

Duit, R. (2009). *Bibliography—STCSE. Students' and teachers' conceptions and science education*. Retrieved 7 July 2010, from http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html.

Duschl, R. A., & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. *Journal of Research in Science Teaching, 26*(6), 467–501.

Eisenhardt, K. M. (2002). Building theories from case study research. In A. M. Huberman & M. B. Miles (Eds.), *The qualitative researcher's handbook* (pp. 5–35). Thousand Oaks, CA: Sage Publications, Inc.

Fensham, P., Gunstone, R., & White, R. (1994). Part I. Science content and constructivist views of learning and teaching. In P. Fensham, R. Gunstone, & R. White (Eds.), *The content of science* (pp. 1–8). London: The Falmer Press.

Flores, F., Lopez, A., Gallegos, L., & Barojas, J. (2000). Transforming science and learning concepts of physics teachers. *International Journal of Science Education, 22*(2), 197–208.

Gallagher, J. J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education, 75*(1), 121–133.

Geelan, D. R., Wildy, H., Louden, W., & Wallace, J. (2004). Teaching for understanding and/or teaching for the examination in high school physics. *International Journal of Science Education, 26*(4), 447–462.

Gunstone, R. F. (2000). Constructivism and learning research in science education. In D. Phillips (Ed.), *Constructivism in education: Opinions and second opinions on controversial issues* (pp. 254–280).

Chicago, Ill: National Society for the Study of Education: Distributed by the University of Chicago Press.

Gunstone, R., & Mulhall, P. (2009, April). *Teaching for understanding in a prescribed physics curriculum: A comparison of learning outcomes in conceptual change and traditional classroooms*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (NARST), Garden Grove, CA.

Gunstone, R., Mulhall, P., & McKittrick, B. (In preparation). *Considering complexities in teaching mechanics and electricity*. Dordrecht, The Netherlands: Springer.

Gustafson, B. J., & Rowell, P. M. (1995). Elementary preservice teachers: Constructing conceptions about learning science, teaching science and the nature of science. *International Journal of Science Education, 17*(5), 589–605.

Hashweh, M. Z. (1996). Effects of science teachers' epistemological beliefs in teaching. *Journal of Research in Science Teaching, 33*(1), 47–63.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., & Lemberger, J. (1999). Educating prospective teachers of biology: Findings, limitations, and recommendations. *Science Education, 83*(3), 373–384.

Kagan, D. M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks principle. *Review of Educational Research, 60*(3), 419–469.

Kang, N.-H. (2008). Learning to teach science: Personal epistemologies, teaching goals, and practices of teaching. *Teaching and Teacher Education, 24*(2), 478–498.

Leach, J., & Scott, P. (2002). Designing and evaluating science teaching sequences: An approach drawing upon the concept of learning demand and a social constructivist perspective on learning. *Studies in Science Education, 38*(1), 115–142.

Linder, C. J. (1992). Is teacher-reflected epistemology a source of conceptual difficulty in physics? *International Journal of Science Education, 14*(1), 111–121.

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–613.

Markic, S., & Eilks, I. (2008). A case study on German first year chemistry student teachers' beliefs about chemistry teaching, and their comparison with student teachers from other science teaching domains. *Chemistry Education Research and Practice, 9*, 25–34.

Matthews, M. R. (1992). Constructivism and empiricism: An incomplete divorce. *Research in Science Education, 22*, 299–307.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (Eds.). (1998). *Teaching science for understanding: A human constructivist view*. San Diego, CA: Academic Press.

Miyake, N. (2008). Conceptual change through collaboration. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 453–478). New York: Routledge.

Mulhall, P. (2005). *Physics teachers' views about physics and learning and teaching physics*. Unpublished PhD thesis, Monash University, Clayton, Victoria, Australia.

Mulhall, P., & Gunstone, R. (2008). Views about physics held by physics teachers with differing approaches to teaching physics. *Research in Science Education*, *38*(4), 435–462.

Osborne, J. (1990). Sacred cows in physics—towards a redefinition of physics education. *Physics Education, 25*(4), 189–196.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307–322.

Pierce, R., & Stacey, K. (2010). Mapping pedagogical opportunities provided by mathematics analysis software. *International Journal of Computers for Mathematical Learning, 15*(1), 1–20.

Prawat, R. S. (1989). Teaching for understanding: Three key attributes. *Teaching and Teacher Education, 5*(4), 315–328.

Prawat, R. S. (1992). Teachers' beliefs about teaching and learning: A constructivist perspective. *American Journal of Education, 100*(3), 354–395.

Scott, P. H., Asoko, H. M., & Driver, R. H. (1991). Teaching for conceptual change: A review of strategies. In R. Duit, H. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 310–329). Kiel: Institute for Science Education.

Scott, P. H., & Driver, R. H. (1998). Learning about science teaching: Perspectives from an action research project. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education. Part one* (pp. 67–80). Dordrecht: Kluwer.

Tobin, K. (1998). Issues and trends in the teaching of science. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education. Part one* (pp. 129–151). Dordrecht: Kluwer.

Tobin, K., & McRobbie, C. J. (1996). Cultural myths as constraints to the enacted science curriculum. *Science Education, 80*(2), 223–241.

Tobin, K., McRobbie, C., & Anderson, D. (1997). Dialectical constraints to the discursive practices of a high school physics community. *Journal of Research in Science Teaching, 34*(5), 491–507.

Tsai, C.-C. (2002). Nested epistemologies: Science teachers' beliefs of teaching, learning and science. *International Journal of Science Education, 24*(8), 771–783.

Tsai, C.-C. (2006). Biological knowledge is more tentative than physics knowledge: Taiwan high school adolescents' views about the nature of biology and physics. *Adolescence, 41*(164), 691–703.

Tsai, C.-C. (2007). Teachers' scientific epistemological views: The coherence with instruction and students' views. *Science Education, 91*, 222–243.

Tytler, R. (2007). Re-Imagining science education: Engaging students in science for Australia's future [Electronic Version]. *Australian Education Review*. Retrieved 18 March 2010 from http://research.acer.edu.au/aer/3.

Uzuntiryaki, E., Boz, Y., Kirbulut, D., & Bektas, O. (2010). Do pre-service chemistry teachers reflect their beliefs about constructivism in their teaching practices? *Research in Science Education, 40*(3), 403–424.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137–158.

Veal, W. R. (2004). Beliefs and knowledge in chemistry teacher development. *International Journal of Science Education, 26*(3), 329–351.

Volkmann, M. J., Abell, S., & Zgagacz, M. (2005). The challenges of teaching physics to preservice elementary teachers: Orientations of the professor, teaching assistant, and students. *Science Education, 89*(5), 847–869.

Wallace, J., & Louden, W. (2003). What we don't understand about teaching for understanding: Questions from science education. *Journal of Curriculum Studies, 35*(5), 545–566.

Wildy, H., & Wallace, J. (1995). Changing the variables: An experiment in physics teaching. *Australian and New Zealand Physicist, 32*(8, Suppl), 1–5 (7).