Summary of Research on Experiences Intended to Deepen Teachers' Science Content Knowledge

Studies of two types of experiences were included in the review of research related to deepening teachers' science content knowledge. First, 38 studies investigated the effects of teachers' experience in professional development programs that had deepening teachers' science content knowledge as a goal. Second, five studies examined teaching practice as a context for teachers to deepen their science content knowledge.

Information on how these studies were identified and a summary of the review methodology can be found at:

http://www.mspkmd.net/index.php?page=06_4a-3d2

Effects of Programs Aimed at Deepening Teachers' Science Content Knowledge

Studies of the effects of 38 different interventions designed to deepen teachers' science content knowledge were reviewed. Information about the research studies is displayed in Table 1. Information about the interventions examined in the studies is shown in Table 2.

In all but 1[1] of the 38 studies of interventions intended to deepen teachers' content knowledge, participating teachers' science content knowledge increased. At a minimum, these results provide existence proofs that experiences aimed at deepening teachers' science content knowledge can achieve that goal. It is important, however, to bear in mind that studies with positive effects are probably more likely to be submitted, and possibly more likely to be accepted, for publication than those with no effects or negative effects.

The diversity of the programs investigated across these 38 studies suggests that there are a variety of effective ways of structuring and delivering experiences to deepen teachers' science content knowledge. Close to half of the studies investigated an intervention that included a summer workshop,[2] with several including sessions conducted during the academic year.[3] There were also a few studies that looked at the effects of semester-long courses.[4] Many of the studies

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[1] Chun & Oliver, 2000.

[2] Atwood, Christopher, & McNall, 2005; Basile et al., 2006; Basista & Mathews, 2002; Chun & Oliver, 2000; Clermont, Krajcik, & Borko, 1993; Freeman, Pounders, & Teddlie, 1994; Greenwood & Scribner-MacLean, 1997; Hanley, 2006; Irving, Dickson, & Keyser, 1999; Jones, 1997; Lord & Peard, 1995; Odom, 2001; Puttick & Rosebery, 1998; Radford, 1998; Shymansky et al., 1993; Williamson & Jose, 2008.

[3] Basile et al., 2006; Jarvis & Pell, 2004; Jarvis, Pell, & McKeon, 2003; Jones, 1997; Radford, 1998.

[4] Freeman et al., 2007; Jones, Rua, & Carter, 1998; Nehm & Schonfeld, 2007; Niaz, 2008; Niaz, 2009; Robardey, Allard, & Brown, 1994; Shen, Gibbons, Wiegers, & McMahon, 2007; Tuan & Chin, 1999.

stated that the teachers were learning through hands-on/laboratory work,[5] and a few programs had teachers work on research projects,[6] sometimes with scientists.

The programs that were studied also differed in the grade range of participating teachers and the science content that was addressed. Positive effects were found for experiences with teachers from elementary, middle, and high school grades variously targeting earth, life, and physical science. On the whole, there is more empirical evidence regarding interventions for elementary grades teachers than for middle or high school teachers. Over half of the reviewed studies examined programs for elementary grades teachers,[7] and interestingly, almost all of these focused on physical science.[8] There is no clear explanation for the overrepresentation of these kinds of studies, but the emphasis is consistent with teachers' own reports of their content backgrounds; elementary teachers are much more likely to report weak content knowledge in physical science than in either life or earth science.[9]

In more than half of the studies,[10] the interventions were described in detail, which is helpful for understanding teachers' experiences and interpreting the link between the intervention and the effects on teachers' science content knowledge. In the rest of the studies,[11] however, the intervention was described only partially, making it more difficult to support these interpretations.

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[5] Alonzo, 2002; Clermont et al., 1993; Freeman et al., 1994; Greenwood & Scribner-MacLean, 1997; Irving et al., 1999; Jarvis & Pell, 2004; Jarvis et al., 2003; Jones, 1997; Jones et al., 1998; Pardhan & Wheeler, 2000; Radford, 1998; Robardey et al., 1994; Summers & Kruger, 1994; Summers, Kruger, Mant, & Childs, 1998; Wang, 2001.

[6] Lord & Peard, 1995; Odom, 2001; Puttick & Rosebery, 1998; Radford, 1998.

[7] Alonzo, 2002; Atwood, et al., 2005; Basista & Mathews, 2002; Clermont et al., 1993; Freeman et al., 1994; Greenwood & Scribner-MacLean, 1997; Heller, Daehler, & Shinohara, 2003; Jarvis & Pell, 2004; Jarvis et al., 2003; Jones, 1997; Jones et al., 1998; Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2008; Pardhan & Wheeler, 2000; Puttick & Rosebery, 1998; Radford, 1998; Robardey et al., 1994; Schibeci & Hickey, 2000; Shen et al., 2007; Shymansky et al., 1993; Storti, 1999; Summers & Kruger, 1994; Summers et al., 1998; Wang, 2001.

[8] Alonzo, 2002; Atwood, et al., 2005; Clermont et al., 1993; Freeman et al., 1994; Greenwood & Scribner-MacLean, 1997; Heller et al., 2003; Jarvis & Pell, 2004; Jarvis et al., 2003; Jones et al., 1998; Lee et al., 2008; Pardhan & Wheeler, 2000; Puttick & Rosebery, 1998; Schibeci & Hickey, 2000; Shen et al., 2007; Summers & Kruger, 1994; Summers et al., 1998.

[9] Fulp, 2002.

[10] Atwood et al., 2005; Clermont et al., 1993; Freeman et al., 2007; Irving et al., 1999; Jones, 1997; Jones et al., 1998; Lee et al., 2008; Lord & Peard, 1995; Monet & Etkina, 2008; Nehm & Schonfeld, 2007; Niaz, 2008; Niaz, 2009; Odom, 2001; Puttick & Rosebery, 1998; Radford, 1998; Schibeci & Hickey, 2000; Shen et al., 2007; Sherman, Byers, & Rapp, 2008; Shymansky et al., 1993; Summers & Kruger, 1994; Tuan & Chin, 1999; Wang, 2001.

[11] Alonzo, 2002; Basile et al., 2006; Basista & Mathews, 2002; Chun & Oliver, 2000; Dole, Clark, Wright, Hilton, & Roche, 2008; Drechsler & van Driel, 2008; Freeman et al., 1994; Greenwood & Scribner-MacLean, 1997; Hanley, 2006; Heller et al., 2003; Jarvis & Pell, 2004; Jarvis et al., 2003; Pardhan & Wheeler, 2000; Robardey et al., 1994; Storti, 1999; Summers et al., 1998; van Driel, Verloop, & de Vos, 1998; Williamson & Jose, 2008.

The interventions varied widely in the level of commitment required of participants, from as few as 6 hours to as many as 160 hours. In a handful of instances, the intervention was not described fully enough to determine the duration.[12] Among those for which duration was described, most were conducted over a week or longer.[13] Generalizability of findings from these studies must be interpreted cautiously, because the populations that these teachers represent are limited to teachers willing and able to commit to participation in such extensive interventions.

[12] Chun & Oliver, 2000; Dreschler & van Driel, 2008; Pardhan & Wheeler, 2000; van Driel et al., 1998.

[13] Atwood et al., 2005; Basile et al., 2006; Basista & Mathews, 2002; Clermont et al., 1993; Dole et al., 2008; Drechsler & van Driel, 2008; Freeman et al., 1994; Freeman et al., 2007; Greenwood & Scribner-MacLean, 1997; Hanley, 2006; Irving et al., 1999; Jarvis & Pell, 2004; Jarvis et al., 2003; Jones, 1997; Jones et al., 1998; Lee et al., 2008; Lord & Peard, 1995; Monet & Etkina, 2008; Nehm & Schonfeld, 2007; Niaz, 2008; Niaz, 2009; Odom, 2001; Puttick & Rosebery, 1998; Radford, 1998; Robardey et al., 1994; Shen et al., 2007; Sherman et al., 2008; Shymansky et al., 1993; Tuan & Chin, 1999; Williamson & Jose, 2008.

Table 1
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Study Characteristics

	Purpose of Study		Data types		Knowledge Outcomes			Measures of Teacher Content Knowledge				Measurement Description		
Name of Study	Program Evaluation	Providing Examples	Quantitative	Qualitative	Disciplinary Content	Ways of Knowing	Pedagogical Content	Assessments	Interviews	Observations	Other Approach	Validity	Reliability	Triangulation
Evaluation of a model for supporting the development of elementary school teachers' science content knowledge (Alonzo, 2002)	•		•	•	•			•	•	•				
Elementary teachers' understanding of standards-based light concepts before and after instruction (Atwood et al., 2005)			•		•		•	•						
The veritable quandary of measuring teacher content knowledge in a math and science partnership. (Basile et al., 2005)	•			•	•		•	•						
Integrated science and mathematics professional development programs (Basista & Mathews, 2002)	•		•	•	•		•	•		•				
A quantitative examination of teacher self-efficacy and knowledge of the nature of science (Chun & Oliver, 2000)	•		•			•		•[a]						
The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators (Clermont et al., 1993)		•		•			•		•				•	
Eliciting growth in teachers' proportional reasoning: Measuring the impact of a professional development program (Dole et al., 2008)		•		•	•		•				•			
Experienced teachers' pedagogical content knowledge of teaching acid-base chemistry (Drechsler & van Driel, 2008).		•		•	•		•		•					
Evaluation of a summer science institute for elementary teachers (Freeman et al., 1994)	•		•		•			•						
How old is the Earth? An exploration of geologic time through place-based inquiry (Freeman et al., 2007).		•	•		•			•				•	•	
Examining elementary teachers' explanations of their science content knowledge (Greenwood & Scribner-MacLean, 1997)	•			•	•			•						

Table 1 (continued)
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Study Characteristics

Name of Study	Purpose of Study		Data types		Knowledge Outcomes			Measures of Teacher Content Knowledge				Measurement Description		
	Program Evaluation	Providing Examples	Quantitative	Qualitative	Disciplinary Content	Ways of Knowing	Pedagogical Content	Assessments	Interviews	Observations	Other Approach	Validity	Reliability	Triangulation
Evaluating science curricula for higher education and professional development (Hanley, 2006)	•		•		•			•						
Connecting all the pieces (Heller et al., 2003)	•		•	•	•			•	•					
Retraining public secondary science teachers by upgrading their content knowledge and pedagogical skills (Irving et al., 1999)		•	•		•			•						
Urban elementary school teachers' knowledge and practices in teaching science to English language learners (Lee et al., 2008)	•		•	•	•		•		•	•			•	•
Primary teachers' changing attitudes and cognition during a two-year science in-service programme and their effect on pupils (Jarvis & Pell, 2004) Changes in primary teachers' science knowledge and understanding during a two year in-service programme (Jarvis et al., 2003)	•		•		•			•				•	•	
Organization, implementation, and results of an Eisenhower systemic elementary science reform project (Jones, 1997)	•		•		•			•						
Science teachers' conceptual growth within Vygotsky's zone of proximal development (Jones et al., 1998)	•		•	•	•			•						
Scientist-teacher summer workshops can enhance constructivist views about science and science instruction (Lord & Peard, 1995)	•		•			•		•						
Fostering self-reflection and meaningful learning: Earth science professional development for middle school teachers (Monet & Etkina, 2008)	•		•	•	•		•	•			•	•	•	•
Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? (Nehm & Schonfeld, 2007)		•	•	•	•	•	•	•				•	•	

Table 1 (continued)
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Study Characteristics

	Purpose of Study		Data types		Knowledge Outcomes			Measures of Teacher Content Knowledge				Measurement Description		
Name of Study	Program Evaluation	Providing Examples	Quantitative	Qualitative	Disciplinary Content	Ways of Knowing	Pedagogical Content	Assessments	Interviews	Observations	Other Approach	Validity	Reliability	Triangulation
What ideas about science should be taught in school science? A chemistry teachers' perspective (Niaz, 2008) Progressive transitions in chemistry teachers' understanding of nature of science based on historical controversies (Niaz, 2009)	•			•		•		•				•	•	•
Inquiry-based field studies involving teacher-scientist collaboration (Odom, 2001)	•		•		•	•		•					•	
Taking "STOCK" of pedagogical content knowledge in science education (Pardhan & Wheeler, 2000)		•	•		•			•						
Teacher professional development as situated sense-making: A case study in science education (Puttick & Rosebery, 1998)		•		•	•			•	•	•				
Transferring theory into practice: A model for professional development for science education reform (Radford, 1998)	•		•		•	•		•					•	
An assessment of the effectiveness of Full Option Science System training for third- through sixth-grade teachers (Robardey et al., 1994)	•		•		•			•						
Is it natural or processed? Elementary school teachers and conceptions about materials (Schibeci & Hickey, 2000)		•		•	•			•				•	•	
Using research-based assessment tools in professional development in current electricity (Shen et al., 2007)		•	•	•	•			•						
Evaluation of online, on-demand science professional development material involving two different implementation models (Sherman et al., 2008)	•		•	•	•			•						

Table 1 (continued)
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Study Characteristics

Name of Study	Purpose of Study		Data types		Knowledge Outcomes			Measures of Teacher Content Knowledge				Measurement Description		
	Program Evaluation	Providing Examples	Quantitative	Qualitative	Disciplinary Content	Ways of Knowing	Pedagogical Content	Assessments	Interviews	Observations	Other Approach	Validity	Reliability	Triangulation
A study of changes in middle school teachers' understanding of selected ideas in science as a function of an in-service program focusing on student perceptions (Shymansky et al., 1993)	•		•		•			•				•	•	
Short-term teacher workshops: Examining the assumption of teacher-to-student transfer (Storti, 1999)		•	•		•			•				•	•	
A longitudinal study of a constructivist approach to improving primary school teachers' subject matter knowledge in science (Summers & Kruger, 1994)	•		•		•			•	•					
Developing primary teachers' understanding of energy efficiency (Summers et al., 1998)		•		•	•			•	•					
What can inservice Taiwanese science teachers learn and teach about the nature of science? (Tuan & Chin, 1999)	•		•			•		•[a]					•	
Developing science teachers' pedagogical content knowledge (van Driel et al., 1998)		•		•			•			•	•	•		
Improving elementary teachers' understanding of the nature of science and instructional practice (Wang, 2001)	•			•		•		•				•		
The effects of a two-year molecular visualization experience on teachers' attitudes, content knowledge, and spatial ability (Williamson & Jose, 2008)	•		•	•	•			•						

[a] Indicates use of an existing measure that was not developed specifically for the purpose of this study.

Table 2
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Intervention Characteristics

		Intervention[a]					Science Content			
Name of Study	Grade Level	Full description	Teacher involvement voluntary	STEM faculty involved	Researcher(s) designed	Researcher(s) delivered	Earth sciences	Life sciences	Physical sciences	Various sciences
Evaluation of a model for supporting the development of elementary school teachers' science content knowledge (Alonzo, 2002)	3	N	Y	?	N	N			•	
Elementary teachers' understanding of standards-based light concepts before and after instruction (Atwood et al., 2005)	K–5	Y	Y	?	N	N			•	
The veritable quandary of measuring teacher content knowledge in a math and science partnership. (Basile et al., 2005)	6–8	N	?	Y	N	N				•
Integrated science and mathematics professional development programs (Basista & Mathews, 2002)	4–10	N	?	Y	Y	Y				•
A quantitative examination of teacher self-efficacy and knowledge of the nature of science (Chun & Oliver, 2000)	6–8	N	?	?	N	N				•
The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators (Clermont et al., 1993)	4–12	Y	Y	N	Y	?			•	
Eliciting growth in teachers' proportional reasoning: Measuring the impact of a professional development program (Dole et al., 2008)	6–8	N	?	?	N	N			•	
Experienced teachers' pedagogical content knowledge of teaching acid-base chemistry (Drechsler & van Driel, 2008).	9–12	N	Y	Y	Y	Y			•	
Evaluation of a summer science institute for elementary teachers (Freeman et al., 1994)	K–5	N	?	?	N	N			•	
How old is the Earth? An exploration of geologic time through place-based inquiry (Freeman et al., 2007).	6–12	Y	Y	Y	N	N	•			
Examining elementary teachers' explanations of their science content knowledge (Greenwood & Scribner-MacLean, 1997)	K–5	N	Y	N	Y	Y			•	
Evaluating science curricula for higher education and professional development (Hanley, 2006)	K–12	N	Y	Y	Y	Y				•
Connecting all the pieces (Heller et al., 2003)	K–5	N	?	?	Y	?			•	
Retraining public secondary science teachers by upgrading their content knowledge and pedagogical skills (Irving et al., 1999)	6–12	Y	Y	Y	N	N		•		

Table 2 (continued)
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Intervention Characteristics

		Intervention[a]					Science Content			
Name of Study	Grade Level	Full description	Teacher involvement voluntary	STEM faculty involved	Researcher(s) designed	Researcher(s) delivered	Earth sciences	Life sciences	Physical sciences	Various sciences
Primary teachers' changing attitudes and cognition during a two-year science in-service programme and their effect on pupils (Jarvis & Pell, 2004) Changes in primary teachers' science knowledge and understanding during a two year in-service programme (Jarvis et al., 2003)	K–5	N	?	?	Y	?			•	
Organization, implementation, and results of an Eisenhower systemic elementary science reform project (Jones, 1997)	K–5	Y	Y	?	?	N				•
Science teachers' conceptual growth within Vygotsky's zone of proximal development (Jones et al., 1998)	K–8	Y	Y	N	Y	N			•	
Urban elementary school teachers' knowledge and practices in teaching science to English language learners (Lee et al., 2008)	3	Y	Y	Y	N	N			•	
Scientist-teacher summer workshops can enhance constructivist views about science and science instruction (Lord & Peard, 1995)	9–12	Y	Y	Y	?	N				•
Fostering self-reflection and meaningful learning: Earth science professional development for middle school teachers (Monet & Etkina, 2008)	6–8	Y	Y	Y	Y	Y	•			
Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? (Nehm & Schonfeld, 2007)	6-12	Y	Y	Y	N	N		•		
What ideas about science should be taught in school science? A chemistry teachers' perspective (Niaz, 2008) Progressive transitions in chemistry teachers' understanding of nature of science based on historical controversies (Niaz, 2009)	9–12	Y	Y	Y	Y	Y			•	
Inquiry-based field studies involving teacher-scientist collaboration (Odom, 2001)	6–12	Y	Y	Y	N	N		•		
Taking "STOCK" of pedagogical content knowledge in science education (Pardhan & Wheeler, 2000)	K–5	N	?	?	?	N			•	
Teacher professional development as situated sense-making: A case study in science education (Puttick & Rosebery, 1998)	K–5	Y	Y	?	Y	Y			•	
Transferring theory into practice: A model for professional development for science education reform (Radford, 1998)	4–10	Y	Y	Y	Y	Y		•		

Table 2 (continued)
Studies of Interventions to Deepen Teachers' Science Content Knowledge: Intervention Characteristics

Name of Study	Grade Level	Intervention[a]: Full description	Intervention[a]: Teacher involvement voluntary	Intervention[a]: STEM faculty involved	Intervention[a]: Researcher(s) designed	Intervention[a]: Researcher(s) delivered	Science Content: Earth sciences	Science Content: Life sciences	Science Content: Physical sciences	Science Content: Various sciences
An assessment of the effectiveness of Full Option Science System training for third- through sixth-grade teachers (Robardey et al., 1994)	3–6	N	Y	?	Y	?				●
Is it natural or processed? Elementary school teachers and conceptions about materials (Schibeci & Hickey, 2000)	K–5	Y	?	?	Y	N			●	
Using research-based assessment tools in professional development in current electricity (Shen et al., 2007)	K–8	Y	Y	Y	Y	Y			●	
Evaluation of online, on-demand science professional development material involving two different implementation models (Sherman et al., 2008)	6–8	Y	Y	Y	N	N			●	
A study of changes in middle school teachers' understanding of selected ideas in science as a function of an in-service program focusing on student perceptions (Shymansky et al., 1993)	4–9	Y	Y	?	Y	N				●
Short-term teacher workshops: Examining the assumption of teacher-to-student transfer (Storti, 1999)	3–9	N	Y	?	N	N	●			
A longitudinal study of a constructivist approach to improving primary school teachers' subject matter knowledge in science (Summers & Kruger, 1994)	K–5	Y	Y	?	Y	?			●	
Developing primary teachers' understanding of energy efficiency (Summers et al., 1998)	K–5	N	Y	?	Y	Y			●	
What can inservice Taiwanese science teachers learn and teach about the nature of science? (Tuan & Chin, 1999)	?	Y	Y	?	N	Y				●
Developing science teachers' pedagogical content knowledge (van Driel et al., 1998)	9–12	N	Y	N	Y	Y			●	
Improving elementary teachers' understanding of the nature of science and instructional practice (Wang, 2001)	K–5	Y	Y	?	Y	?				●
The effects of a two-year molecular visualization experience on teachers' attitudes, content knowledge, and spatial ability (Williamson & Jose, 2008)	9–12	N	?	Y	Y	Y				●

[a] Y = Yes, N = No, ? = Not clear from document

The Evidentiary Base for Claims about Programs Aimed at Deepening Teachers' Science Content Knowledge

Seven of the reviewed studies measured outcomes in both disciplinary content knowledge and pedagogical content knowledge.[14] Four others targeted knowledge of ways of knowing in science in addition to disciplinary content knowledge.[15] Otherwise, though, studies restricted their focus to knowledge in only one of these domains, either disciplinary content,[16] ways of knowing[17] or pedagogical content.[18] Across the studies the level of disciplinary content knowledge that was addressed in the interventions varied. For the most part, teachers engaged with the content they teach their students, at the level they are expected to teach it. In a few studies, by contrast, the disciplinary content was either beyond what teachers typically teach or addressed in substantially greater depth.[19]

It is important to recognize that particular features of the interventions, although described in detail in some cases and logically tied to the reported impacts on teachers' science content knowledge, were not investigated in any of the studies through either systematic or naturalistic variation. Findings in these studies can be understood to result only from teachers' experience of the programs as a whole. Similarly, effects of specific experiences on different facets of teachers' content knowledge were not systematically examined in any of these studies.

Since different instruments were used to assess teachers' science content knowledge across the studies, it is not possible to compare results on a common outcome measure to identify whether features of one program may be more or less effective for a particular purpose than features of another program. Claims that some features are important for deepening teachers' science content knowledge are suggested to some extent by their presence in the multiple programs studied. The importance of these features in deepening particular facets of teachers' content knowledge was also supported on logical or theoretical grounds in some studies. However, the contributions of particular features to effects on different facets of teachers' content knowledge cannot be strongly concluded from the empirical evidence in these studies.

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[14] Atwood et al., 2005; Basile et al., 2006; Basista & Mathews, 2002; Dole et al., 2008; Drechsler & van Driel, 2008; Lee et al., 2008; Monet & Etkina, 2008.

[15] Nehm & Schonfeld, 2007; Niaz, 2008; Niaz, 2009; Radford, 1998.

[16] Alonzo, 2002; Freeman et al., 1994; Freeman et al., 2007; Greenwood & Scribner-MacLean, 1997; Hanley, 2006; Heller et al., 2003; Irving et al., 1999; Jarvis & Pell, 2004; Jarvis et al., 2003; Jones, 1997; Jones et al., 1998; Odom, 2001; Pardhan & Wheeler, 2000; Puttick & Rosebery, 1998; Robardey et al., 1994; Schibeci & Hickey, 2000; Shen et al., 2007; Sherman et al., 2008; Shymansky et al., 1993; Storti, 1999; Summers & Kruger, 1994; Summers et al., 1998; Wang, 2001; Williamson & Jose, 2008.

[17] Chun & Oliver, 2000; Lord & Peard, 1995; Tuan & Chin, 1999; Wang, 2001.

[18] Clermont et al., 1993; van Driel et al., 1998.

[19] Alonzo, 2002; Basista & Mathews, 2002; Freeman et al., 1994; Freeman et al., 2007; Niaz, 2008; Niaz, 2009; Puttick & Rosebery, 1998; Radford, 1998; Summers & Kruger, 1994; Summers et al., 1998; Williamson & Jose, 2008.

Another important consideration for interpreting the results of several of the studies was involvement of researchers in the interventions, either as developers,[20] deliverers,[21] or both.[22] When researchers deliver interventions, it is more likely that they are implemented as intended. However, these researchers, whether developers or deliverers, may have a vested interest in study outcomes, potentially introducing biases toward evidence of intended outcomes. Also, implementation of the programs may have included aspects that remained implicit and would therefore not appear in researchers' descriptions, making replication of the interventions very difficult.

Although all of the studies in this review used either a pre-post design to measure changes in teachers' content knowledge or traced changes in teachers' content knowledge over multiple points in time, only one of the studies used comparison groups of teachers who did not participate in the professional development programs.[23] Given the experience levels of many of the participating teachers, the extent of professional development provided, and the nature of the measured changes, it is certainly reasonable to argue that the changes resulted from the interventions, but without comparisons to other teachers these claims are not solidly grounded in empirical evidence. For example, it is possible that the teachers might perform better on a measure of content knowledge on a post-test simply because they had completed it previously, in one case[24] taking the same test at the beginning and end of the same workshop day. The use of multiple measures addresses this concern to some extent, for example in several studies which used both written instruments and interviews with teachers to assess impacts on teachers' content knowledge.[25]

Teaching Practice as a Context for Deepening Teachers' Science Content Knowledge

This review included five studies that investigated whether teachers can deepen their science content knowledge as a result of their teaching practice itself. One was a case study of a new teacher,[26] another followed four new teachers through their first year on the job,[27] two focused on the effects of a new curriculum on teachers' knowledge,[28] and the final study investigated the

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[20] Clermont et al., 1993; Heller et al., 2003; Jones et al., 1998; Robardey et al., 1994; Schibeci & Hickey, 2000; Shymansky et al., 1993; Summers & Kruger, 1994; Wang, 2001.

[21] Tuan & Chin, 1999.

[22] Basista & Mathews, 2002; Drechsler & van Driel, 2008; Greenwood & Scribner-MacLean, 1997; Hanley, 2006; Monet & Etkina, 2008; Niaz, 2008; Niaz, 2009; Puttick & Rosebery, 1998; Radford, 1998; Shen et al., 2007; Summers et al., 1998; van Driel et al., 1998; Williamson & Jose, 2008.

[23] Lee, et al., 2008

[24] Storti, 1999.

[25] Alonzo, 2002; Heller, 2003; Puttick & Rosebery, 1998; Summers & Kruger, 1994; Summer et al., 1998.

[26] Tuan & Kaou, 1997.

[27] Gee & Gabel, 1996.

[28] Cohen & Yarden, 2009; Henze, van Driel, & Verloop, 2008.

effects of the National Board certification process on teachers' knowledge.[29] All of these studies showed at least some positive results on deepening teachers' pedagogical content knowledge, and one also reported positive effects on deepening teachers' disciplinary content knowledge.[30] Table 3 provides information about the research studies, and Table 4 displays information about the interventions examined in these studies.

All five of the studies examining teaching practice as a contributor to deepening teachers' science content knowledge documented positive effects. The five studies investigated various features of teaching practice, suggesting that multiple aspects of practice may serve as potential contributors to content knowledge gains. Four of the studies examined secondary school teachers, together spanning grades 6-12, with attention across the four studies to earth, life, and physical science.[31] The other study examined elementary school teachers' knowledge in various science disciplines.[32] Four of the 5 studies[33] used classroom observations and/or interviews to examine teachers' science content knowledge in relation to their teaching practice, with only one using a written assessment instrument.[34] Although the number of studies is small, there is at least a suggestion that teacher learning of content from practice is possible at multiple grade levels. However, no empirical evidence is available to suggest how teachers' learning from their practice might differ for content knowledge in one discipline of science versus another.

All of the identified studies that investigated teacher learning from practice included pedagogical content knowledge as an outcome of interest; three also examined disciplinary content knowledge[35] and one of these also attended to teachers' knowledge of ways of knowing in science.[36] In all five studies, at least some positive results were reported for each outcome that was investigated, suggesting that teacher learning from practice may include multiple facets of science content knowledge. However, it is worth noting that studies with positive effects are probably more likely to be submitted, and perhaps more likely to be accepted, for publication than those with no effects or negative effects.

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[29] Lustick & Sykes, 2006.

[30] Gee & Gabel, 1996.

[31] Cohen & Yarden, 2009; Henze et al., 2008; Lustick & Sykes, 2006; Tuan & Kaou, 1997.

[32] Gee & Gabel, 1996.

[33] Cohen & Yarden, 2009; Henze et al., 2008; Lustick & Sykes, 2006; Tuan & Kaou, 1997.

[34] Gee & Gabel, 1996.

[35] Gee & Gabel, 1996; Henze et al., 2008; Tuan & Kaou, 1997.

[36] Henze et al., 2008.

The Evidentiary Base for Claims about Teaching Practice as a Context for Deepening Teachers' Mathematics Content Knowledge

The main purposes of the five studies of teaching practice were to illustrate and substantiate how teachers can learn science content through their teaching practice. Each of the five studies involved only a small number of teachers, collected only post-experience data, and did not investigate systematic variations, so claims regarding causation or generalizability can be only weakly supported. The common finding in these studies that teaching practice presents a context in which teachers can learn science content suggests, however, that efforts to deepen teachers' content knowledge might expand their impact by attending to the context of teaching practice as a site for learning. By providing appropriate structures, resources, and opportunities to support learning, professional development efforts intended to deepen teachers' science content knowledge might take advantage of teachers' ongoing work in their schools and classrooms to bolster their content learning.

A variety of methods were used the five studies to measure teacher content knowledge, including written assessments, interviews, observations, and analysis of classroom artifacts, such as lesson plans. The use of different methods across the studies suggests that the findings may be robust. At the same time it is difficult to compare or combine results across the studies since the outcome measures are quite different, and information on validity and reliability was absent or very limited in these studies. Because this is a fairly new area of investigation, the illustrations of teachers' science content learning in these exploratory studies are a key contribution to building theory about teacher learning from practice.

A few issues regarding validity and generalizability in these studies should also be noted. In four of the studies, systematic methods of analyses were described that included important elements such as establishing reliability among researchers, member checking qualitative results with research participants, and describing discrepant results and possible alternative explanations.[37] Four of the studies included potential for investigator bias because the investigators had specific relationships with the research subjects or had other possible interests in the outcomes of the research At the same time, the investigators revealed the relationships they had with the research subjects and these relationships may have facilitated collection of detailed and trustworthy data through observations and interviews.[38]

Since the samples for three of the studies were quite small[39] and in these three cases and one other,[40] also of unknown representativeness of broader populations of teachers, the studies do not support further generalizability of the results. As exploratory studies, generalizability was not a primary concern. It is important to bear in mind that the teachers participating in these studies were committed to programs to support improvement and/or investigation of their practice, and that much of their learning may have derived not only from their practice but also from the opportunities they had to reflect on their practice with colleagues and the investigators.

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[37] Cohen & Yarden, 2009; Henze et al., 2008; Lustick & Sykes, 2006; Tuan & Kaou, 1997.

[38] Cohen & Yarden, 2009; Gee & Gabel, 1996; Henze et al., 2008; Tuan & Kaou, 1997.

[39] Henze et al., 2008; Lustick & Sykes, 2006; Tuan & Kaou, 1997.

[40] Cohen & Yarden, 2009.

Findings in these five studies, commensurate with the purpose of exploratory research, provide a basis for theorizing about teacher learning from practice, and are intriguing as hypotheses to investigate further. Causality is not strongly established by the empirical evidence. Generalizability is mainly supported by thorough descriptions that can be compared to the readers' own experiences with teachers.

Table 3
Studies of Deepening Teachers' Science Content Knowledge Through Their Instructional Practice: Study Characteristics

	Purpose of Study		Data Types		Knowledge Outcomes			Measures of Teacher Content Knowledge				Measurement Description		
Name of Study	Program Evaluation	Providing Examples	Quantitative	Qualitative	Disciplinary Content	Ways of Knowing	Pedagogical Content	Assessments	Interviews	Observations	Other Approach	Validity	Reliability	Triangulation
Experienced junior high school teachers' PCK in light of a curriculum change: The cell is to be studied longitudinally (Cohen & Yarden, 2009)	•			•			•		•	•	•			•
The first year of teaching: Science in the elementary school (Gee & Gabel, 1996)		•		•	•		•	•						
Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe (Henze et al., 2008)		•		•	•	•	•		•					
National Board Certification as professional development: What are teachers learning? (Lustick & Sykes, 2006)	•			•			•		•	•			•	
Development of a grade eight Taiwanese physical science teacher's pedagogical content knowledge development (Tuan & Kaou, 1997)		•		•	•		•		•	•	•	•		

Table 4
Studies of Deepening Teachers' Science Content Knowledge Through Their Instructional Practice: Intervention Characteristics

Name of Study	Grade Level	Intervention[a]				Science Content			
		Full description	Voluntary Teacher Involvement	STEM Faculty Involved	Researcher(s) Involved	Earth Sciences	Life Sciences	Physical Sciences	Various Sciences
Experienced junior high school teachers' PCK in light of a curriculum change: The cell is to be studied longitudinally (Cohen & Yarden, 2009)	6–8	Y	?	N	Y		•		
The first year of teaching: Science in the elementary school (Gee & Gabel, 1996)	K–5	Y	N	?	N				•
Henze Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe (Henze et al., 2008)	9–12	N	Y	Y	Y	•			
Lustick National Board Certification as professional development: What are teachers learning? (Lustick & Sykes, 2006)	6–12	N	Y	?	N				•
Development of a grade eight Taiwanese physical science teacher's pedagogical content knowledge development (Tuan & Kaou, 1997)	8	Y	Y	N	N			•	

[a] Y = Yes, N = No, ? = Not clear from document

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Additional information on how these studies were identified and reviewed, a summary of the methodology can be found at:

http://www.mspkmd.net/index.php?page=06_4a-3d2

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