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Providing support focused on real challenges is critical in retaining highly qualified new science teachers, but the field lacks a systematic description of these teachers' needs. The authors of this article examine the areas that science teachers are expected to understand: (1) the content and disciplines of science, (2) learners, (3) instruction, (4) learning environments, and (5) professionalism. They review the literature on challenges facing preservice and early-career science teachers, identify issues on which conventional wisdom is supported or called into question, and highlight the areas where the existing research is inadequate as a basis for generalization. For example, the authors found few studies on how new science teachers use curriculum materials or how they understand scientific inquiry. Their overview of challenges is followed by a discussion of how these teachers can be supported.

Keywords: new teachers, science teachers, teaching challenges.

In this review, we explore the challenges that new science teachers face as they embark on their teaching careers. Specifically, we ask, What are the challenges that new science teachers face in trying to meet the increasingly high expectations laid out for them in current reform documents? Understanding how it might be challenging for teachers to meet those expectations may help others to provide them with appropriate support.

When we say *new teachers,* we include *preservice teachers* (either students in schools of education or individuals in alternative certification programs) as well as teachers in their first 5 years of practice. We do so in keeping with a view of learning to teach as a continuum, as opposed to a set of distinct chapters in a teacher's life (Feiman-Nemser, 2001). When we need to be specific—for example, in describing the participants in a study or the findings cutting across studies—we distinguish between these groups, using the term *early-career teachers* to indicate those who are already practicing.

Perspective of the Review

We hold that education is about promoting learning and that teacher education (including professional development as well as preservice teacher preparation) is about promoting learning among teachers. Teachers must achieve learning goals.

But just as students face challenges in achieving the goals set for them, so teachers, too, face challenges in learning. If teacher educators do not understand their learners' needs, then their instructional approaches will be hit-or-miss.

The contribution of this review, then, is a systematic catalogue of the challenges that new science teachers face. One purpose is to help teacher educators and others concerned about teacher learning to make instructional and curricular decisions based not on assumptions or conventional wisdom but instead on the actual research base. Another purpose is to help researchers identify areas in which further research is warranted.

We assume that being a new teacher will always be hard. Although the review points to many areas in which new teachers do not yet measure up to the standards being set for them, we take this as a reasonable state of affairs. New teachers are, by definition, novices working toward expertise. Our perspective is that though the standards may reflect what (new) teachers should be able to do, teacher educators, policymakers, education researchers, and administrators are not yet doing enough to help them meet those expectations. Again, we hold that a better understanding of the areas in which the most support is needed will help those concerned with teacher learning focus their resources more effectively and efficiently.

Choices Made in This Review

We necessarily made choices about which teachers to study as we embarked on this review. Our first decision point has to do with level of experience. While it is important to support all teachers in enacting reforms, it may be especially critical to support *new* teachers. Our choice is grounded in part in the prevalence of discussion of teacher education at the national level in the United States (see, e.g., Cochran-Smith & Zeichner, 2005). Early-career teachers leave the profession at alarmingly high rates. Almost 20% of teachers under the age of 30 leave the profession (Bobbitt, Leich, Whitener, & Lynch, 1994); the odds of these young teachers departing their teaching jobs are 171% higher than are the odds for middle-aged teachers (Ingersoll, 2001). Yet new teachers are crucial for enacting and spreading reforms—many learn about current reform movements in their teacher education programs and thus seem most likely to be able to adopt and promote reform-oriented instruction. Supporting them in doing so effectively would help to make their early years of teaching more effective, thus improving the instruction that students receive. Moreover, providing new teachers with additional support might help eventually to stem the tide of attrition.

We chose to focus on *science* teachers because so much of teaching is inherently domain-specific. Furthermore, new science teachers' challenges may lead them to experience job dissatisfaction. Though the turnover rates for new math and science teachers are not significantly higher than they are for other teachers, when asked about reasons for leaving their current teaching jobs, math and science teachers cite job dissatisfaction at a higher rate than do other teachers who are also leaving (Ingersoll, 2001).

Finally, we include new *elementary as well as secondary* teachers in this work. "Science teacher" typically connotes a secondary teacher of, say, biology, chemistry, or physics. But new elementary teachers may face even greater challenges in teaching science than do their secondary counterparts, since they typically teach multiple subjects, including all areas of science. We wanted to be able to describe what challenges are common across grade level in addition to showing how elementary and secondary teachers differ.

Throughout our review, we note areas that further research could inform. In the last 15 years, related reviews have focused on preservice science teachers' subject matter knowledge and pedagogical content knowledge (Cochran & Jones, 1998), science teacher education (Anderson & Mitchener, 1994; Northfield, 1998; see also Clift & Brady, 2005), science teachers' views of the nature of science (Lederman, 1992), and, across subject areas, competent beginning teaching (Reynolds, 1992), learning to teach (Kagan, 1992; Munby & Russell, 1998; Wideen, Mayer-Smith, & Moon, 1998), and professional development experiences (Marx, Freeman, Krajcik, & Blumenfeld, 1998; Wilson & Berne, 1999). None of these reviews, however, looks specifically at the expectations and challenges facing new science teachers.

Expectations for New Science Teachers

What do we expect new science teachers to know and be able to do? Let us start by considering expectations for science teachers; new science teachers, presumably, are expected to do the same sorts of things as experienced teachers, perhaps with less proficiency. Current science teaching reforms (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996) emphasize helping students to develop deep conceptual understandings of learning goals while also conveying the nature of science by engaging students in authentic scientific inquiry—a very tall order. Teachers must devise experiences that will help students construct understandings of natural phenomena, as well as assessments that demonstrate evidence of student learning to numerous constituencies. Science teachers are expected to help all of their students to succeed, respecting and drawing productively on students' diverse ideas, including those at odds with normative science ideas. Finally, they must situate their students' learning within the broader context of their school, neighborhood, town, or city, and the nation as a whole.

To describe these expectations more systematically, we turned to three sets of standards. The Interstate New Teacher Assessment and Support Consortium (INTASC) has developed a set of core standards for new teachers (1992) as well as a set of science-specific standards (2002). The National Science Education Standards (NSES) for teaching include standards for science teachers regardless of experience level (NRC, 1996). By seeing how these map on to one another, we see what is expected of new science teachers. The INTASC (2002) and NSES standards for science teaching are summarized in Appendixes A and B.

The current emphasis on standards is controversial. Wang and Odell (2002) note several reasons for the controversy surrounding standards for *student* (not teacher) achievement: concerns about blame shifting, social justice, and the undermining of teachers' decision making and intellectual engagement with teaching, to name just a few. Yet Wang and Odell go on to state that "in spite of these worries, few critics disagree with the basic principles of standards-based teaching reform, principles that focus on what students need to know and how they come to know it" (p. 484). It is for similar reasons that we see these standards for *teaching* as appropriate to use as a frame for our work: They concisely represent the kinds of things that teachers should probably be able to do—and indeed, that teacher educators should help them achieve—and are the result of some form of consensus-building at a higher level than a single scholar's viewpoint.

We conducted a content analysis of the INTASC (1992, 2002) and NSES (NRC, 1996) standards to identify major themes to use as an organizational frame for this review. Our first step was to group the INTASC standards into tentative themes. We grouped together INTASC Standards 2 and 3 as having to do with learners. We grouped Standard 4, about instructional variety, with Standard 7, about planning and making curricular decisions, and Standard 8, about assessment, because all three relate to a broader definition of instruction. Similarly, we grouped Standards 5 and 6 as having to do with the classroom culture and learning environment—acknowledging that distinguishing among learners, instruction, and the learning environment itself is difficult. Finally, we grouped Standards 9 and 10 as having to do with the broader goal of becoming a professional. We then mapped pieces of the NSES standards onto these themes. In sum, the analysis yields five main themes addressing what teachers are expected to understand: (1) the content and disciplines of science, (2) learners, (3) instruction, (4) learning environments, and (5) professionalism. Table 1 summarizes how each theme relates to the standards; each is elaborated in the review of the challenges that teachers face. Note that the INTASC standards describe not just knowledge that teachers should hold, but also goals for dispositions and performances. Our meaning of "understand" is intended to encompass all three of these dimensions.

These five themes are analytic categories that are useful for the research endeavor. In reality, all of them are interrelated, and certainly other groupings are possible. We describe the effects of these interrelationships and ambiguities in the Methods section.

Methods

We searched seven journals: *American Educational Research Journal; Journal of Research in Science Teaching; Journal of Science Teacher Education; Journal of Teacher Education; Journal of the Learning Sciences; Science Education;* and *Teaching and Teacher Education.* We selected these journals because they are leaders both within the scope of our review and in education research as a whole.

Inclusion Criteria and Review Process

We systematically looked at every paper published in each of these journals between 1993 and 2004, identifying papers relating to new science teachers and the

TABLE 1
Themes identified in INTASC and NSES science teaching standards

	Standards on which the theme draws	
Theme	INTASC	NSES
1—Understanding the content and disciplines of science	1	A, B, E
2—Understanding learners	2, 3	A, B, E
3—Understanding instruction	4, 7, 8	All
4—Understanding learning environments	5, 6	A, B, D, E
5—Understanding professionalism	9, 10	C, F

challenges they face. We also searched the ERIC database, using relevant search terms, to identify studies published elsewhere during the same time period. This process identified more than 180 papers to include in our database. We reviewed papers starting in 1993 because the INTASC (1992) standards were released in 1992 and the Project 2061 *Benchmarks for Science Literacy* (AAAS, 1993) were released in 1993. Thus the early 1990s were a time of increasing emphasis on standards for reform-oriented teaching.

We selected only empirical studies that focused on new science teachers and that addressed one or more of the themes that we had identified in our analysis of the standards documents. We included papers from any country and did not purposefully look for papers that represented a particular theoretical perspective or methodological approach. A paper was excluded from the review if, on the basis of more careful review (described below), it was deemed irrelevant to our analytic themes. A paper could also be excluded if it exhibited flaws such as a poor methodology or poorly substantiated conclusions. All of the journals that we searched use peer review, but editorial norms have varied over the years and we determined that we needed to impose a post-hoc peer review in a few cases; this process eliminated three papers from our corpus. (In two cases, the studies involved extremely limited data from a single preservice teacher; in the other case, we felt that a series of methodological flaws, combined with the development of conclusions not based on data presented in the paper, warranted the paper's exclusion.) Finally, a paper could be excluded from the review if it focused mainly on ways of supporting new teachers but not on challenges; such papers could be included in the later brief discussion of supports.

What does this set of inclusion and exclusion criteria mean for the papers that are included in this review? Regrettably, the criteria resulted in the elimination of many interesting papers—for example, those that focused on new mathematics teachers or experienced science teachers or descriptions of innovative new programs. But by focusing the review on new science teachers, we can delve more deeply into these teachers' challenges than we would otherwise be able to do.

If we deemed a paper to be potentially relevant, then one or two authors read the paper. One entered a summary of the paper in our database, and the other (if applicable) contributed additional comments or clarifications to the entry. If a paper was controversial or questionable in any way, a third author read the paper, as well.

In determining which theme or themes a paper addressed, we regularly referred to the definitions in the standards themselves. We used our judgment in instances where there was not an explicit fit. We erred on the side of being inclusive so that nothing would be missed. Thus papers regularly were coded as relevant to more than one theme.

Because much of the teacher education literature is based on case studies of small numbers of teachers (Wilson & Berne, 1999; Zeichner, 1999), we alert readers to differences in scale. We do not intend to place more value on either large- or small-scale studies. Both have strengths and limitations. But readers can better weigh for themselves the claims we make if they know something about the scale of the studies. Furthermore, some claims may be backed up by several studies, while others may be based on a single study. Therefore, we are clear about how much empirical evidence there is for a claim, and we note counterevidence. We make claims only if we feel that they are warranted by the evidence in the studies.

In addition, if a claim applies only to, say, preservice elementary teachers, we say so explicitly.

The resulting review of challenges incorporates 112 unique, individual studies. We provide a complete list of the papers ultimately included in the review of challenges, with information on number and type of participants, in Appendix C. Each paper that we deemed appropriate for our review of challenges is cited at least once within the review. If a paper on which we elaborate does not necessarily represent the findings of all the other papers cited in a set, we use the phrase "for example" to flag this rhetorically. These briefly elaborated papers serve to illustrate overarching trends or provide counterevidence to such trends. Most important, because the five themes we identified in the standards are interrelated—for example, one cannot hold a meaningful understanding of science instruction (Theme 3) without also understanding one's learners (Theme 2)—the studies do not always fit neatly into one theme or another. Thus we sometimes discuss a study in the context of multiple themes, to convey a fuller flavor of the study and the themes; and we sometimes elaborate on a study within only one theme, while citing it in multiple places. Readers inevitably will see cases where they feel a study might fit into a different section. Bearing in mind the inherent relationships among the themes will help readers to benefit more from the review.

Structure of This Article

In most of the remainder of this article, we review the challenges that new science teachers face, organized along the five themes. We also provide commentary on those challenges. Table 2 summarizes how many papers we identified for each theme and presents other descriptive data summarizing the studies. At the end of this article, we highlight examples of support for new teachers in overcoming some of the challenges; we then recommend next steps.

TABLE 2
Numbers of papers by themes and study characteristics

Theme or study characteristics	Theme 1	Theme 2	Theme 3	Theme 4	Theme 5	Total unique papers
Number of papers	59	25	48	17	30	112
Mean *n* participants	120.3	20.8	14.3	30.4	68.2	74.8
Median *n* participants	27	6	4	11	14	15
Grades taught						
Elementary	34 (57.6)	10 (40.0)	19 (39.6)	6 (35.3)	19 (63.3)	58 (51.8)
Secondary	22 (37.3)	12 (48.0)	25 (52.1)	10 (58.8)	10 (33.3)	48 (42.9)
Both	2 (3.4)	3 (12.0)	3 (6.3)	1 (5.9)	1 (3.3)	5 (4.5)
Career stage						
Preservice	51 (86.4)	22 (88.0)	35 (72.9)	9 (52.9)	22 (73.3)	92 (82.1)
Early career	5 (8.5)	1 (4.0)	10 (20.8)	7 (41.2)	7 (23.3)	15 (13.4)
Both	3 (5.1)	2 (8.0)	3 (6.3)	1 (5.9)	1 (3.3)	5 (4.5)

Note. Percentages are given in parentheses. Mismatches in sums are due to unavailable information (see Appendix C).

Theme 1: Challenges Related to Understanding the Content and Disciplines of Science

The first theme, *understanding the content and disciplines of science,* focuses on the teacher's understanding of "the major concepts, assumptions, debates, processes of inquiry, and ways of knowing that are central" to the science discipline(s) she teaches (INTASC, 1992, p. 14). The teacher should realize that scientific knowledge is always changing and understand how that knowledge is generated (INTASC, 1992). The studies presented in Theme 1, then, explore a critical question about new science teachers: How do these teachers understand science, broadly construed, and what lays the foundation for that understanding? We organize these papers into four areas: (a) the teachers' experiences and academic preparation in science; (b) substantive knowledge of science content; and ideas about (c) science inquiry and (d) the nature of science. These papers generally confirm conclusions of earlier reviews (see Cochran & Jones, 1998; Lederman, 1992), indicating that new teachers have relatively weak understandings of science overall. Holes in the literature's coverage, however, make some generalizations impossible. Furthermore, some studies provide counterevidence that raises a dissenting view about the sophistication of teachers' ideas.

Theme 1 is the most heavily populated theme, in terms of number of papers (59) as well as mean (approximately 120) and median (27) number of participants (see Table 2). Most of the studies (58%) involve only elementary teachers and most (92%) involve preservice teachers as at least some of the participants.

Experiences and Academic Preparation in Science

Being prepared adequately, in terms of coursework in science, seems likely to be critical for becoming an effective science teacher. Two studies focused on academic preparation. One surveyed 211 early-career teachers in Grades 6–12 and found that about 61% of all the teachers had at least 18 hours of coursework in their major teaching area (LaTurner, 2002). About 26% of the total sample lacked certification and had fewer than 18 hours of coursework in their majors. Another study investigated undergraduates' academic preparation in science, comparing 96 elementary education students with 179 arts and sciences students (Young & Kellogg, 1993). The authors described similar enrollment patterns in science courses in the two groups, and found that the elementary education majors earned higher grades in their science and math courses than did the arts and sciences students. However, the students also typically reported having had negative experiences in their science courses. Nonetheless, these two studies show a less dire view of teachers' academic preparation than is typically assumed in the literature.

Other studies—most of which involve preservice elementary teachers—focused more squarely on experiences in science (Howes, 2002; Hynd, Alvermann, & Qian, 1997; Powell, 1994; Smith, 2000; Smith & Anderson, 1999; Sullenger et al., 2000). For example, Smith and Anderson differentiated among the 9 preservice elementary teachers in their study, characterizing them as either "knowers" of or "wonderers" about science. The "knowers" (who had previous positive experiences with science) tended to focus on facts, getting the right answer, and getting things to work correctly; the "wonderers" (who had not had positive experiences with science in the past) tended to value the opportunity to try things out for themselves and discover scientific knowledge. In other words, surprisingly (and in contrast to the other studies in this set), those with more negative previous experiences were more open to exploration in science. In another study, Howes focused on 4 preservice elementary teachers; they reported many negative science experiences. They also reported, however, some important positive experiences that had helped them to realize that they were interested in the world around them. These studies yielded no single characterization of teachers' experiences in science: The preservice (mostly elementary) teachers had positive and negative experiences with science, and both kinds of experiences seemed to play important roles. In addition, two studies characterized preservice teachers who choose a science concentration (Lord & Holland, 1997; Sutton, Watson, Parke, & Thomson, 1993). For example, a study of 62 preservice elementary teachers found that past experience (e.g., in science classes) was the most important factor in deciding whether they would concentrate in science (Sutton et al., 1993).

Other papers touched on, but looked less centrally at, teachers' academic preparation and/or experiences with science (e.g., Bianchini, Johnston, Oram, & Cavazos, 2003; Carlsen, 1993; Enochs, Scharmann, & Riggs, 1995; Gess-Newsome & Lederman, 1993; Ginns & Watters, 1995; Lederman, Gess-Newsome, & Latz, 1994; Lynch, 1997; Rosebery & Puttick, 1998; Stoddart, Connell, Stofflett, & Peck, 1993; Windschitl, 2003). For example, Windschitl found, in his study of 6 preservice secondary teachers, that the teachers who used inquiry in their own teaching each had previous long-term research experience themselves.

In sum, new science teachers' preparation and experiences are mixed but are not uniformly negative. Teachers' experiences affect their perceptions of science and their likelihood of concentrating in science teaching. Studies focusing explicitly on academic preparation, however, are limited in number.

Substantive Knowledge of Science Content

In light of concerns about whether new teachers have adequate knowledge of the subjects they teach, we characterized new teachers' substantive knowledge of science (Schwab, 1964). We identified three main types of studies here, focused on knowledge of specific science topics, understandings of science content more generally, and teachers' perceptions of their knowledge. All of these studies involved preservice teachers; most were focused at the elementary level.

First, many researchers have investigated new teachers' knowledge and understandings of specific science topics, including light (Bendall, Goldberg, & Galili, 1993), the water cycle (Stoddart et al., 1993; Stofflett & Stoddart, 1994), matter (Ginns & Watters, 1995), energy (Trumper, Raviolo, & Shnersch, 2000), multiple topics in chemistry (Haidar, 1997 [the only one of these studies to involve secondary teachers]), the seasons (Atwood & Atwood, 1996, 1997), the phases of the moon (Trundle, Atwood, & Christopher, 2002), day and night (Atwood & Atwood, 1997), and multiple topics in astronomy (Trumper, 2003). These studies ranged from 27 individuals in one study (Stofflett & Stoddart, 1994) to 645 in another (Trumper, 2003). Though the previous section indicated that teachers may not be underprepared in terms of coursework, in almost all of the studies reviewed here, the teachers were found to have unsophisticated understandings of science. The teachers held "a range of inaccurate scientific concepts" (Ginns & Watters, 1995, p. 219) or "widely inadequate conceptions" (Stofflett & Stoddart, 1994, p. 39). For example, in a study of 645 preservice elementary teachers' conceptions of multiple astronomy topics, the overall correct response rate was only 36% (Trumper, 2003). In general, the preservice teachers held alternative ideas that were similar to those that have been identified in students (Bendall et al., 1993; Ginns & Watters, 1995; Schoon & Boone, 1998; Trumper, 2003). Even secondary preservice teachers showed poor understandings of topics (Haidar, 1997).

Second, researchers have investigated teachers' knowledge and understandings of science content more generally (Carlsen, 1993; Gess-Newsome & Lederman, 1993; Lederman & Latz, 1995; Lederman et al., 1994; McDevitt, Troyer, Ambrosio, Heikkinen, & Warren,1995; Smith, 1999; Yerrick, Doster, Nugent, Parke, & Crawley, 2003). These typically small-scale studies focus on an individual discipline (e.g., biology, chemistry) or more than one discipline, rather than being limited to specific science topics. In contrast to the emphasis on preservice elementary teachers in the studies of specific science topics, these studies mostly involve secondary teachers. For example, two studies by Gess-Newsome, Lederman, and colleagues (Gess-Newsome & Lederman, 1993; Lederman et al., 1994) found that the preservice secondary science teachers in their studies initially lacked understanding of the connections between concepts in the disciplines they were to teach; but these understandings improved over time and with experience. (In contrast, the 12 preservice secondary MAT teachers in a study conducted by Lederman and Latz held more extensive subject matter knowledge than the other preservice teachers studied by this research group; furthermore, these MAT preservice teachers' ideas did not become better integrated over time.)

Finally, researchers have looked at elementary and secondary preservice teachers' perceptions of their substantive knowledge in science or motivations for their own learning of science (Ellis, 2001; Gess-Newsome & Lederman, 1993; Hynd et al., 1997; Lederman et al., 1994; Rice & Roychoudhury, 2003; Smith & Anderson, 1999). For example, in Rice and Roychoudhury's study of 52 preservice elementary teachers, about 60% of the teachers felt that their subject matter knowledge was weak.

In sum, preservice teachers seem, for the most part, to lack adequate understandings of science content. This trend is especially pronounced at the elementary level; results are more mixed at the secondary level. Though most studies do not characterize change over time, those that do indicate that the preservice teachers' knowledge may improve over time.

Knowledge and Beliefs About Science Inquiry

To teach inquiry-oriented science as recommended by current reforms in science education, a teacher must also hold strong understandings of and abilities with regard to science inquiry. We defined inquiry broadly to include science process skills and higher-order thinking skills, as well as inquiry abilities such as questioning, predicting, explaining, and communicating findings (NRC, 2000). Most of the studies we found—again, conducted with preservice teachers—did not look at teachers' inquiry abilities per se, but rather at the other kinds of skills (Boone & Gabel, 1998; Lawrenz & Gray, 1995; Lawson, 2002; Lee, 1993; McDevitt et al., 1995; Roth, McGinn, & Bowen, 1998). For example, one study looked at 22 preservice secondary biology teachers and their hypothesis-testing performance (Lawson, 2002). The preservice teachers could construct arguments to test hypotheses when the hypotheses involved observable entities (e.g., pendulums) but not when they involved unobservable phenomena (e.g., evolution). A few other researchers looked at inquiry much more broadly, beyond the process and thinking skills emphasized above (Shapiro, 1996; Smith, 1999; Windschitl, 2003). For example, Windschitl investigated 6 preservice secondary teachers' conceptions of inquiry and found that some had a fairly realistic view of inquiry while others viewed inquiry as a linear, lock-step process. Shapiro found that the elementary preservice teacher chosen as representative of 21 preservice teachers in the larger study had trouble asking appropriate scientific questions. Overall, these papers illustrate that many preservice teachers have unsophisticated understandings of inquiry and related skills, though of course individuals vary.

Knowledge and Beliefs About Science and the Nature of Science

Teachers' knowledge of and beliefs about science and the nature of science has been a rich area of research over the last decade, especially for preservice teachers. The papers in this area demonstrate a wide range of sample sizes and a variety of methodologies, ranging from case studies of a handful of teachers to questionnaires given to hundreds of participants.

The studies in this area consistently find that most (though not all) new teachers have naive beliefs about the nature of science (see Lederman, 1992, for a review). Researchers describe various dimensions of these beliefs, including beliefs about how science is conducted (i.e., whether there is a universal scientific method; Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Powell, 1997; Rubba & Harkness, 1993), how scientific knowledge is constructed (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Lemberger, Hewson, & Park, 1999; Lin & Chen, 2002; Meyer, Tabachnick, Hewson, Lemberger, & Park, 1999; Smith, 2000), the nature of scientific knowledge (i.e., whether scientific knowledge is tentative or subjective; Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Arellano, Barcenal, Bilbao, Castellano, Nichols, & Tippins, 2001; Lemberger et al., 1999; Meyer et al., 1999), and other dimensions (Abd-El-Khalick & Lederman, 2000; Akerson et al., 2000; Ebenezer, 1996; Richmond, Howes, Kurth, & Hazelwood, 1998; Rubba & Harkness, 1993). For example, studies of 15 preservice secondary teachers and 166 college students in a history of science course (Abd-El-Khalick & Lederman, 2000) and of 30 Middle Eastern preservice elementary teachers (Abd-El-Khalick, 2001) found that about 25–27% of each of the three groups initially believed in a universal scientific method. A study of 6 elementary preservice teachers in the Philippines found that the preservice teachers tended to believe that science textbooks presented "the truth" (Arellano et al., 2001). Ebenezer investigated 4 Christian preservice elementary teachers' beliefs; a belief in absolute (spiritual) truth caused conflict for them when they considered the nature of science and constructivist science teaching.

A few studies investigated preservice teachers' attitudes toward science (Cobern & Loving, 2002; McDevitt, Heikkinen, Alcorn, Ambrosio, & Gardner, 1993; Settlage, 2000; Smith, 2000; Sullenger et al., 2000). One study found that, in the sample of the almost 700 elementary preservice teachers surveyed, there was "no hint" (p. 1027) of an anti-science attitude in which science is viewed negatively; rather, the authors argue, the preservice teachers' attitudes toward science were complex, reasonable, and justified (Cobern & Loving, 2002). This stands in contrast to Sullenger and colleagues' report on a course aimed at the nature of science; the authors found that some of the 5 preservice elementary and secondary teachers who participated in the course and then in the research held strongly anti-science attitudes. The main finding from this latter study, though, seemed to be that discussing the nature of science can be emotionally charged for preservice teachers.

Though many of the studies reviewed above suggest that new science teachers' beliefs about the nature of science are not very sophisticated, a few studies complicate these findings (Bianchini & Solomon, 2003; Bianchini et al., 2003; Hammrich, 1997; Palmquist & Finley, 1997; Powell, 1994; Simmons et al., 1999; Smith & Anderson, 1999). Overall, these papers indicate that there are differences among and even within individuals (i.e., an individual can have sophisticated beliefs about some dimensions of the nature of science while holding less sophisticated beliefs about others) and illustrate the possibility for change over time. These studies (along with the much larger Cobern & Loving, 2002, study of teachers' attitudes reported above) may show that new teachers' views are more complex than some other research suggests.

Summary and Commentary for Theme 1

What does this review tell us about how new science teachers understand science? First, we found limited results about new teachers' academic preparation in science and mixed results regarding their experiences with science. Based on limited evidence, it appears that teachers may have adequate numbers of science courses. Negative experiences with science can alienate new teachers from science, but positive experiences in traditional science courses may lead them to naive understandings of the nature of science.

Second, as is typically assumed in the literature, preservice teachers demonstrated relatively unsophisticated knowledge of specific science topics and (less consistently) of science disciplines more generally. Almost all of the work on science topics, though, has explored preservice elementary teachers' knowledge of physical and earth science topics.

Finally, even though inquiry-oriented science teaching is a major aspect of current reforms in science teaching, relatively little work has been done on science inquiry as defined by the NRC (2000) and others. Some studies investigating preservice teachers' knowledge of science processes or thinking skills indicate that these teachers' knowledge would be inadequate to prepare them for teaching through science inquiry. Nevertheless, there is a great deal of research on beliefs about science and the nature of science. Overall, this research, too, indicates that new teachers hold relatively unsophisticated beliefs, which would cause difficulties in portraying science appropriately. Some evidence, however, suggests that these beliefs—while not necessarily sophisticated—may be more complicated, well reasoned, and justified than most of the studies imply.

In what areas would the field benefit from additional research? There has been little research on early-career teachers' knowledge, secondary teachers' knowledge of any specific science topics, or elementary teachers' knowledge of life science topics. The field also needs further research characterizing new teachers' preparation in and experiences with science. It may be especially important to learn more about the preparation of elementary teachers because they teach the life, physical, and earth sciences to children, yet may take few science courses.

Furthermore, as noted above, few studies explicitly characterized teachers' knowledge of specific inquiry abilities, such as asking and answering scientific questions, making explanations based on evidence, and communicating and justifying findings. Without understanding scientific inquiry, new teachers are unlikely to be successful in teaching through inquiry. Continuing the research that unpacks the nuances of teachers' understandings of the nature of science seems productive in working toward this end, as well.

Theme 2: Challenges Related to Understanding Learners

Theme 2, *understanding learners,* focuses on teachers' understanding of how students learn and develop, and includes an appreciation of the variation in learners and in how they approach learning (INTASC, 1992). Teachers should believe that *all* students can "learn at high levels" (INTASC, 1992, p. 18), regardless of their cultural and language backgrounds. Teachers should "recognize and respond to student diversity and encourage all students to participate fully in science learning" (NRC, 1996, p. 32), and they should "display and demand respect for the diverse ideas, skills, and experiences of all students" (NRC, 1996, p. 46). The studies presented in this section, then, explore another important challenge for new science teachers: How do these teachers understand students' science learning and development and consider them as science learners with ideas, backgrounds, and experiences to be taken seriously?

Theme 2 draws on far fewer studies than did Theme 1 (25 as opposed to 59). Again, most of the studies involve preservice teachers as participants; these studies tend to be much smaller-scale than those included in Theme 1, with a median number of participants of 6 (see Table 2). We organize these studies into two broad areas: teachers' knowledge, beliefs, and practices about (a) learners and learning, in general, and (b) diverse learners, in particular. Overall, as the following two sections demonstrate, new science teachers' ideas about learners can become more sophisticated with time and support, but in general these teachers struggle with understanding their learners; in addition, their practices with regard to their learners are often naive.

Students and How They Learn Science

Preservice elementary teachers recognize that paying attention to students as learners is important (Abell, Bryan, & Anderson, 1998; Howes, 2002; Meyer et al., 1999; Peterson & Treagust, 1998). For example, Meyer and colleagues studied 3 preservice elementary teachers and found that each of them recognized that it was important to identify learners' ideas. (The teachers had different purposes for doing so, however.) Howes studied 13 preservice elementary teachers (and reported on 4 focus teachers). Howes found that although the preservice teachers started out with a straightforward love of children, they came to care, in addition, about children's thinking.

Another theme, however, is that preservice teachers tend not to consider students or student learning very extensively, very carefully, or in very sophisticated ways (Abell et al., 1998; Edwards & Ogden, 1998; Geddis, Onslow, Beynon, & Oesch, 1993; Peterson & Treagust, 1998; Zembal-Saul, Blumenfeld, & Krajcik, 2000). For example, many of the 49 preservice elementary teachers studied by Abell and colleagues mainly valued student interest and motivation, and the 2 preservice secondary chemistry teachers in Geddis and colleagues' study were surprised when their students did not already know how to calculate the average atomic mass of an element, an integral prerequisite for their successful participation in the lessons. Early teaching experiences helped the preservice teachers in some of these studies come to recognize the importance of anticipating students' ideas.

Some studies characterize not the extent of but the *nature* of preservice elementary and secondary teachers' knowledge and beliefs about students as learners. Southerland and Gess-Newsome (1999) studied 22 preservice elementary teachers and found that they tended to believe that learners have fixed abilities, which led them to place students in categories (e.g., high and low ability), tailor instruction to those perceived abilities (e.g., students who are perceived as high-ability might be permitted to engage in research projects), and not revisit the categorization, so that categories were possibly reinforced over time (see also Geddis & Roberts, 1998, for another example of student categorization). Other studies describe the varied nature of teachers' views of learning (Abell et al., 1998; Gurney, 1995; Lemberger et al., 1999; Meyer et al., 1999). Gurney investigated 151 preservice secondary teachers and identified four main perspectives on learning, which can be seen as a process of delivery (in which learners receive a message), change (in which learners become different as a result of learning), enlightenment (in which the hidden potential of students is revealed through learning), or humanics[1] (in which learning involves interaction, struggle, and persistence). Overall, the papers in this set conform to Gurney's overarching finding and indicate that preservice teachers hold varied perspectives on learners and learning; no single, consistent perspective emerged.

A few studies described change in preservice elementary and secondary teachers' beliefs during teacher education (Anderson, Smith, & Peasley, 2000; Tabachnick & Zeichner, 1999; van Driel, de Jong, & Verloop, 2002; Zembal-Saul et al., 2000). For example, Anderson and her colleagues studied 3 preservice elementary teachers and found that 2 of them ended up having fairly sophisticated understanding of learners and learning, even though they took different paths over time; the third did not make progress. Van Driel and colleagues studied 12 preservice secondary teachers and found that they developed an improved understanding of learners' ideas about macro- and micro-scale representations in chemistry. With support, then, we see that preservice teachers can develop improved understandings of learners and learning.

Other papers investigate the teachers' *practices* with regard to students as learners. The preservice elementary and secondary teachers tended to have very limited ideas about what to do, instructionally, with students' ideas (Mellado, 1998; Tabachnick & Zeichner, 1999; Zembal-Saul et al., 2000). For example, in Zembal-Saul and colleagues' study, the 2 preservice elementary teachers responded poorly to the students in their first cycle of planning, enacting, and reflecting on a lesson and did not gain an understanding of students' thinking while they were teaching—perhaps as a result of not having planned with students in mind in the first place. Their thinking and practices changed in the second cycle; they tried (not very successfully) to account for learners' ideas in their planning and enactment.

Diverse Learners and Science for All

One important aspect of understanding learners is recognizing the ways in which learners are similar to and different from one another. Here, we review papers that describe teachers' ideas and practices with regard to diverse learners.

Several papers, taken together, illustrate the range of new teachers' knowledge of or ideas about approaches for teaching science for all (Arellano et al., 2001; Bianchini & Solomon, 2003; Bullock, 1997; Howes, 2002; McDevitt et al., 1995; Rodriguez, 1998; Sweeney, 2001). Rodriguez, for example, studied 18 preservice secondary teachers, including 4 focus teachers, and found that the preservice teachers tended to feel hopeless and overwhelmed about working with diverse students. They tended to show resistance to ideological and pedagogical change, but over time, they came to appreciate the need to make their classroom accessible to all students. One study compared 137 elementary and secondary teachers (both preservice and inservice, including, presumably, some early-career teachers) in terms of their resistance to multicultural science education; the secondary teachers exhibited more resistance to considering multicultural issues than did the elementary teachers (Sweeney, 2001). Arellano and colleagues described how the 6 participating preservice elementary teachers in the Philippines came to appreciate (and begin to work through) issues such as the lack of a shared language among the student population and the importance of connecting to and respecting one's local community.

Some papers went further and characterized teachers' practices with regard to science for all and/or examined how teachers' knowledge and beliefs interacted with their practices (Bianchini et al., 2003; Luft, Bragg, & Peters, 1999; Scantlebury & Kahle, 1993; Southerland & Gess-Newsome, 1999; Yerrick & Hoving, 2003). For example, Bianchini and colleagues investigated 3 early-career secondary teachers and found that they highlighted underrepresented groups in science and worked to teach in equitable ways. Yerrick and Hoving investigated a group of preservice secondary teachers' beliefs about science teaching and learning for lower-track science students. These preservice teachers referred to their own experiences as learners as their guides for good teaching. In addition, some did not shift in their beliefs at all during the methods class. These teachers tended to blame students for believing that school was not important. Other preservice teachers, however, revised their beliefs and rarely attributed failure to the students.

Summary and Commentary for Theme 2

Expert teachers need to be able to understand their students as learners so that they can help them develop understandings and participate in the learning communities of classrooms. The studies reported within this theme show that, in general, new teachers do not have very clear ideas about what to do with regard to students' ideas or backgrounds; at least at the elementary level, preservice teachers seem initially to want mainly to engage, interest, motivate, or manage their students. The preservice elementary teachers do, however, recognize that knowing about these ideas and backgrounds is important. Teacher educators need to consider how to build on new teachers' strengths and devise instructional opportunities that could promote growth in areas of weakness, such as translating some productive ideas into practice.

Overall, most of the studies of teachers' ideas about learners involved preservice teachers and were relatively small in scale. Some areas involved exclusively or predominantly preservice teachers at the elementary or secondary levels, rather than a mix. The field may need more large-scale studies and more studies involving teachers at other levels and/or early-career teachers to complement existing studies. This might require asking new types of questions and developing instruments for measuring teachers' ideas about learners and learning along the lines of the tests and surveys that researchers have already developed for the larger-scale studies of subject matter knowledge and beliefs about the nature of science.

Theme 3: Challenges Related to Understanding Instruction

The third theme, *understanding instruction,* means that the teacher "understands principles and techniques, along with advantages and limitations, associated with various instructional strategies" (INTASC, 1992, p. 20) and "uses a variety of instructional strategies" (INTASC, 2002, p. 4). Theme 3 is not limited to the enactment of instruction; a teacher must be able to plan effectively, "based upon knowledge of subject matter, students, the community, and curriculum goals" (INTASC, 1992, p. 27), and "develop a framework of yearlong and short-term goals for students" (NRC, 1996, p. 30). Finally, the teacher must understand and be able to effectively use multiple methods of formal and informal assessment. Thus the studies included in this section explore how new science teachers understand and engage in planning, instructional strategies, and assessment.

We identified 48 papers for Theme 3. Early-career teachers are better represented here than in the previous two themes (see Table 2), though papers including early-career teachers as participants still only account for about 27% of the papers associated with this theme. The first group of papers generally characterizes teachers' knowledge and beliefs about science teaching. The second group looks at interactions between those ideas about teaching and ideas about science. The third and fourth groups describe aspects of pedagogical content knowledge. The final two groups emphasize teachers' practice, first describing that practice and its interactions with teachers' knowledge and beliefs and then describing science instruction involving low risk for the teachers. Overall, these studies illustrate a mismatch between teachers' ideas and practices—their ideas about instruction seem generally to be more sophisticated and innovative than are their actual practices. The studies also highlight factors that may promote the development of more sophisticated ideas and practices.

Characterizing Teachers' Knowledge and Beliefs About Teaching Science

The papers characterizing teachers' ideas about teaching science highlight differences between what elementary and secondary teachers emphasize. For elementary preservice teachers, we note an emphasis on hands-on activities (Abell et al., 1998; Guillaume, 1995; Howes, 2002; Odom & Settlage, 1996; Peterson & Treagust, 1998). Furthermore, the studies identify teachers' different rationales for using a hands-on approach (Abell et al., 1998; Howes, 2002; Peterson & Treagust, 1998). For example, Abell and her colleagues found that the 49 preservice elementary teachers involved in their study tended to value hands-on science because it motivates and interests the students. A study of 21 preservice elementary teachers (with a focus on 2 teachers) describes one preservice teacher as using hands-on activities to reinforce concepts that were introduced earlier, the other to allow students to explore ideas (Peterson & Treagust, 1998). On the other hand, preservice secondary teachers tend to focus on content and sometimes view instruction as a transmission process (Geddis & Roberts, 1998; Koballa, Graber, Coleman, & Kemp, 1999; Lemberger et al., 1999). For example, Lemberger and colleagues found that all 3 preservice secondary teachers participating in their study thought it was their responsibility to make sure that students left their classes with correct scientific knowledge.

One paper characterized the ways that teachers considered the teaching of science. Abell and her colleagues (1998) found that the 49 preservice elementary teachers' written observations of science teaching and learning lacked evidence to support claims. The teachers also tended to use buzz words without ascribing meaning to them. Poor observation abilities and lack of clarity of meaning could act as obstacles as teachers develop their ideas about instruction.

A few studies described changes in teachers' knowledge and beliefs about teaching science, but the direction or nature of these changes was inconsistent across studies, regardless of the type of teacher being investigated (Donahue, 2000; Guillaume, 1995; Lederman & Latz, 1995; Lederman et al., 1994; Sillman & Dana, 2001; Simmons et al., 1999; Sweeney, Bula, & Cornett, 2001). For example, Simmons and colleagues looked at 69 early-career secondary teachers and found that over time they demonstrated less stability in their beliefs about their actions as teachers, their philosophies of teaching, and their views of themselves as teachers. On the other hand, Sillman and Dana looked at 4 preservice elementary teachers and found that, at the beginning of the first semester of the study (when the preservice teachers were taking their science methods course and pursuing their pre-student-teaching field experiences), the preservice teachers tended to have a didactic view of science teaching and learning. By the middle of the year, they had recognized the importance of hands-on activities—like the elementary teachers described above. By the end of the year (after student teaching), they began to see a larger role for themselves as teachers while developing more student-centered beliefs. One basic challenge that new teachers face is developing sophisticated ideas about science instruction; these papers indicate that though improvement can occur, it is neither guaranteed nor necessarily long-lasting.

Interactions With Knowledge and Beliefs About Science

Theme 1 described teachers' knowledge and beliefs about various aspects of science. This section describes how this knowledge and these beliefs are related to teachers' knowledge and beliefs with regard to instruction. A first group of studies characterized the relationship between teachers' substantive knowledge and their science teaching. In one case, this took the form of deciding *what* to teach. Pankratius (1995) described 1 preservice secondary biology teacher who learned from an experienced biology teacher about the scientific problems with creationism and as a result came to believe that creationism did not have a place in the science classroom. In other instances, the relationship had to do with *how* the teachers taught (Adams & Krockover, 1997b; Carlsen, 1993; Gess-Newsome & Lederman, 1993; Tabachnick & Zeichner, 1999). Carlsen, for example, investigated 4 secondary biology preservice teachers and found that in teaching topics for which their knowledge was low, the teachers asked students more questions. When teaching topics for which their knowledge was greater, however, they asked more demanding questions and gave students more opportunities to speak. In general, these studies—mostly conducted with secondary teachers—indicate that when new teachers have stronger subject matter knowledge, they are more likely to engage in more sophisticated teaching practices.

Other studies focused on the relationship between ideas about the nature of science and one's science teaching (Hammrich, 1997; Powell, 1994; Tabachnick & Zeichner, 1999). Some described ways in which a less sophisticated understanding of the nature of science co-occurred with a less constructivist orientation toward teaching (Hammrich, 1997; Tabachnick & Zeichner, 1999). But even very sophisticated understandings of the nature of science can co-exist with less sophisticated practices. In Powell's study of a former hydrogeologist turned science teacher, the preservice secondary teacher believed that he needed to deliver content to his students despite his own deep understanding of how science is done. One final study involving 76 preservice elementary teachers found that they did not have to overcome negative attitudes about science in order to understand a particular instructional approach in science (Settlage, 2000).

Overall, then, teachers' subject matter knowledge seems related to their instructional ideas and practice; stronger science knowledge typically co-occurs with more sophisticated ideas or practices with regard to instruction (though most of the studies related to this point were conducted with secondary teachers). Preservice teachers' beliefs about and attitudes toward science, though, are inconsistent in the extent to which they serve as predictors of knowledge, beliefs, and practices with regard to instruction.

Science Curriculum and Assessment

One aspect of teachers' pedagogical content knowledge—the special knowledge teachers hold that allows them to teach subject matter (Shulman, 1986)—is their knowledge of science curriculum and assessment (Magnusson, Krajcik, & Borko, 1999). Only one paper focused on knowledge of assessment (Kamen, 1996), but several studies investigated teachers' curricular knowledge (Adams & Krockover, 1997a, 1997b; Geddis et al., 1993; Haney & McArthur, 2002; Southerland & Gess-Newsome, 1999). Understanding which topics are critical and which are tangential helps teachers decide how deeply to cover a topic; without this understanding, the 2 preservice secondary teachers in Geddis and colleagues' study focused on nonessential concepts while short-changing more important ones. The 22 preservice elementary teachers in Southerland and Gess-Newsome's study, though, tended to take the science curriculum as a given; they did not question it or the topics being taught. In addition, a study of 4 preservice secondary teachers found that all of them were concerned about adhering to a local curriculum—and this concern may have influenced them in not giving students much decision-making control in the classroom (Haney & McArthur, 2002). These studies provide a sense of the difficulties entailed in developing curricular knowledge. Surprisingly, we found no studies focused directly on concerns about needing to cover large amounts of content, though some identified this as an issue new teachers face (e.g., Tabachnick & Zeichner, 1999). One study, however, investigated 25 preservice and early-career secondary science teachers' curriculum analyses to check for content alignment with standards documents (Lynch, 1997). The author claims that engaging in the self-critique activity helped the teachers to make reasoned curricular decisions.

We did see an emphasis on addressing the nature of science standards in the classroom—at least among preservice secondary teachers who took courses focused on the nature of science (Bell, Lederman, & Abd-El-Khalick, 2000; Bianchini et al., 2003; Palmquist & Finley, 1997). In general, the papers in this set indicated that these teachers taught their students about the nature of science. One study, though, found that although the 15 preservice elementary teachers agreed conceptually with the reforms espoused in the standards documents, they felt that the time such instruction would take might outweigh the benefits (Hammrich, 1997).

Collectively, these studies point to both the importance of and the obstacles to engaging in principled consideration and refinement of curriculum.

Specific Instructional Strategies, Approaches, Activities, and Representations

Another aspect of science teachers' pedagogical content knowledge is their topic- and subject-specific knowledge of instructional approaches, strategies, and representations for science (Magnusson et al., 1999). Several studies focus on this aspect (Adams & Krockover, 1997a; Edwards & Ogden, 1998; Odom & Settlage, 1996; Settlage, 2000; Sweeney, 2001; van Driel et al., 2002; Yerrick et al., 2003). For example, one highlights a difference between elementary and secondary preservice and inservice teachers (including, presumably, some early-career teachers); the 137 teachers differed in their perspectives on using an instructional approach that involved connecting science to societal issues and incorporating scientific controversies into the curriculum. The elementary teachers were more resistant than the secondary teachers to using this approach (Sweeney, 2001). Two studies focus on preservice teachers' use of instructional representations (van Driel et al., 2002; Yerrick et al., 2003). Without support, preservice teachers may lack the subject matter knowledge to identify effective instructional representations or to develop their own (Yerrick et al., 2003). In van Driel and colleagues' study of 12 preservice secondary teachers, though, the preservice teachers in a program with multiple forms of support (including a workshop that emphasized visualization and representations) reported having successfully helped their chemistry students understand differences between macro and micro representations.

Other papers described a mismatch between preservice teachers' ideas and what they were actually able to accomplish (Geddis et al., 1993; Zembal-Saul et al., 2000; Zembal-Saul, Krajcik, & Blumenfeld, 2002). For example, in Zembal-Saul and colleagues' (2000) study of 2 preservice elementary teachers, the teachers recognized the importance of planning instruction around scientifically accurate instructional representations during their first year in the teacher education program and began doing so. However, the researchers then followed the 2 teachers (and a third) into their student teaching semester, and found that one of the participants from the original study stopped using scientifically oriented representations in her plans once she reached her student teaching classroom, because she became focused instead on day-to-day survival in the classroom (Zembal-Saul et al., 2002).

In sum, new teachers face many challenges with regard to using effective instructional approaches, including lacking relevant subject matter knowledge, not knowing how to enact their instructional ideas, and being resistant to certain innovative practices. With support, though, teachers can begin to move along a positive trajectory.

Practices and Interactions Between Knowledge and Beliefs and Practices

In the papers reviewed in the previous sections, the emphasis was on teachers' knowledge and beliefs, though some also characterized practice. The papers we review in this and the following section emphasize teachers' practice.

New teachers experience struggles and successes in their practice (Abell & Roth, 1994; Ginns & Watters, 1999; Meladdo, 1998; Mulholland & Wallace, 2001; Scantlebury & Kahle, 1993; Zembal-Saul et al., 2000). For example, a study of 1 preservice teacher who was later studied as a first-year elementary teacher found that getting her students to behave drove many of the teacher's decisions (Mulholland & Wallace, 2001). As a preservice teacher, she used demonstrations much of the time because she wanted to maintain control. As a first-semester teacher, she decided to teach a content-free unit toward the beginning of the year because she was worried about the students' behavior. She initially did not think that cooperative lessons (such as those in the curriculum materials she used) would work for her, so she consistently changed lessons to make them more teacher-directed. In contrast, a study of 7 preservice secondary teachers found some of them able to put into practice part of what they had learned about equitable teaching (e.g., asking higher-order questions of both boys and girls; Scantlebury & Kahle, 1993).

Several papers provided evidence that there is a mismatch between new teachers' ideas and their practice (Bradford & Dana, 1996; Bryan & Abell, 1999; Crawford, 1999; Haney & McArthur, 2002; Mellado, 1998; Meyer et al., 1999; Simmons et al., 1999; Southerland & Gess-Newsome, 1999; Sweeney et al., 2001; see also Geddis et al., 1993; Zembal-Saul et al., 2000, 2002, reviewed above). A study of 4 preservice secondary teachers found that, in general, the preservice teachers were able to put beliefs into practice about student negotiation, scientific uncertainty, and personal relevance. On the other hand, they were not able to put into practice their beliefs about involving students in decision-making practices, perhaps because of their belief that they needed to adhere to a local curriculum, as described above (Haney & McArthur, 2002). A study of 22 preservice elementary teachers found that when the preservice teachers were pushed to assess diverse learners, they abandoned the idea of measuring achievement and instead measured effort (Southerland & Gess-Newsome, 1999). These two papers show a tendency for the teachers to hold some beliefs that—when put into practice—conflict with other beliefs. When this happens, one belief may trump another, sometimes leading to less sophisticated teaching practices. Another reason for the mismatch between ideas and practice is that teachers do not always know how to enact practices that are in line with their beliefs. Crawford found that a preservice secondary teacher developed more sophisticated beliefs about science teaching over the course of a year and came to view her role as that of facilitator. By the end of the year, about half of her lessons were inquiry-oriented; the other half involved giving the students information.

Three small studies, each of which involved a single participant, showed how teachers who reflected on their practice were able sometimes to identify the mismatches between their ideas and practice, and sometimes could work to better align their practice with their beliefs (Bradford & Dana, 1996; Bryan & Abell, 1999; Sweeney et al., 2001). We discuss the role of reflection more generally in the section on professionalism (Theme 5).

Conservative Science Teaching and the Avoidance of Science Teaching

Inquiry-oriented science teaching, as recommended by the teaching standards (INTASC, 2002; NRC, 1996), involves taking risks. Yet several studies showed that new teachers (at both the elementary and secondary levels) tended to engage in conservative science teaching and low-risk activities (Appleton & Kindt, 2002; Eick, 2002; Mellado, 1998; Mulholland & Wallace, 2001; Tabachnick & Zeichner, 1999). Some studies showed a relationship between engaging in low-risk activities and having a concern about discipline or classroom management (an issue that we address again in the section on Theme 4). For example, a study of 22 elementary and secondary preservice teachers explored the reasons that teachers tended not to engage in conceptual-change teaching that accounted for and tried to address students' initial ideas (Tabachnick & Zeichner, 1999). For both elementary and secondary teachers, in addition to their concerns about management, constraints also included a naive understanding of the nature of scientific knowledge. Elementary teachers also found that science was not emphasized in their schools and that they sometimes lacked the necessary subject matter knowledge to engage in conceptual change teaching. Secondary teachers also had concerns about covering content. A study of 9 early-career elementary teachers showed that they engaged in science activities that were manageable for them and had predictable outcomes (Appleton & Kindt, 2002). Indeed, an extreme version of engaging in low-risk science activities is not teaching science at all. The elementary teachers in Appleton and Kindt's study could choose what they taught; in addition, science had a low priority in their schools and teachers lacked adequate resources for science teaching. All of these factors meant that the teachers tended not to teach science much unless they were highly motivated to do so.

One study provides a counterpoint to this general trend, though it focuses on only a single teacher (Abell & Roth, 1994). This preservice elementary teacher developed effective coping strategies while taking her science methods course. She infused additional science into an otherwise limited science curriculum and inspired the other teachers in her school to use cooperative learning experiences. Her personal attributes and the features of her student teaching context helped her to take risks in her environment.

Summary and Commentary for Theme 3

We identified a great deal of research focusing on Theme 3, understanding instruction. Our analysis found that elementary teachers tend to emphasize the use of hands-on activities (though for different reasons that do not match science education researchers' rationales). Secondary teachers, while showing variation, tend in general to focus on content. Combining these two emphases would improve teachers' instruction; developing the knowledge and disposition to do so, though, seems to be challenging for new teachers. Teachers with stronger subject matter knowledge tended to employ, or at least consider, more effective or innovative teaching strategies; again, developing adequate subject matter knowledge is challenging for new teachers, and the studies in this section show how inadequate subject matter knowledge can play out in classrooms. Most of these studies involved secondary teachers.

Most of the literature on how new science teachers teach the nature of science focused on secondary teachers and painted a promising picture. The teachers—who typically had participated in teacher education programs emphasizing the nature of science—taught the subject in fairly sophisticated ways. Other teachers, however, may lack much opportunity to learn about the nature of science.

Finally, several studies show that new teachers may have more sophisticated ideas about instruction than they are able to put into practice. Developing the ability to put one's beliefs into practice—and to identify which of one's beliefs are more productive—is hard for teachers.

Overall, the studies indicate that new science teachers tend to teach less reform-oriented science than many science educators would hope. Some teachers, however, develop effective coping strategies or demonstrate success in engaging in effective science teaching practices.

We found little research that focused on how new science teachers deal with the large number of standards they are expected to meet. A related point is that we identified very little research on how new teachers make long-term plans for instruction. There is also a shortage of research on teachers' curricular knowledge (especially for elementary teachers) and knowledge of assessment and instructional strategies.

Finally, since most of the literature on how the nature of science is portrayed in the classroom involved secondary teachers in courses emphasizing the nature of science, it would be helpful to know more about how elementary teachers teach about the nature of science and how secondary teachers from other types of programs do so.

Theme 4: Challenges Related to Understanding Learning Environments

The fourth theme, *understanding learning environments,* emphasizes teachers' understandings of how to set up productive classroom environments for science learning. This involves creating "a learning environment that encourages positive social interaction, active engagement in learning, and self-motivation" (INTASC, 1992, p. 22) and understanding "the principles of effective classroom management and [using] a range of strategies to promote positive relationships, cooperation, and purposeful learning in the classroom" (INTASC, 1992, p. 22). Teachers need to help students accept responsibility for their own learning and must "create a setting for student work that is flexible and supportive of science inquiry" (NRC, 1996, p. 43), "ensure a safe working environment" (NRC, 1996, p. 43), and "make the available . . . resources accessible to students" (NRC, 1996, p. 43). Finally, teachers must use their "knowledge of effective . . . communication techniques to foster active inquiry, collaboration, and supportive interaction," including interactions that are equitable for all students (INTASC, 1992, p. 25).

Theme 4 is closely related to Theme 2, about understanding learners, and especially Theme 3, about understanding instruction. Here, we focus on the culture, atmosphere, or norms of the classroom, having addressed other salient aspects of learning environments in the earlier themes. Thus, in this theme, we review only 17 papers, the fewest in all the themes (see Table 2). It is interesting to note that a much higher proportion of these papers include early-career teachers than is the case for any of the other themes—almost 50%, as opposed to an overall average of less than 20%.

New teachers' creation of classroom learning environments may be most dependent on the way they manage the classroom; for new teachers, this may have a great deal to do with the rules they establish and how they discipline students. But other aspects of the classroom contribute to the effectiveness of the culture, as well, especially when the aim is to create a classroom culture conducive to scientific inquiry.

Thus we divide these papers into those about classroom management and those about effective science learning environments, more generally. The studies reviewed in this section ask, How do new science teachers understand their charge of designing and enacting a productive science learning environment? Overall, these studies indicate that new teachers want their classrooms to be student-centered but that concerns about classroom management may work against that goal.

Classroom Management

Although management typically is billed as a huge struggle for new teachers, only a few papers focused on new science teachers' knowledge and beliefs about the role of management in creating a productive classroom culture (Adams & Krockover, 1997a, 1997b; Ellis, 2001; Geddis & Roberts, 1998). These studies indicate that the new teachers involved were, indeed, concerned about classroom management. Other studies depict teachers' management practices and the relationship between management and other classroom practices (Eick, 2002; Luft, Roehrig, & Patterson, 2003; Mulholland & Wallace, 2001; Tabachnick & Zeichner, 1999; Zuckerman, 2000). A study of 36 middle and high school student teachers describes teachers' management most thoroughly; half of the student teachers either did not respond to management problems they experienced or attempted simply to enforce compliance on the part of the students. In general, their responses to problems were vague, ineffectual, or confrontational (Zuckerman, 2000). Furthermore, concerns about management sometimes drove new teachers' decisions (Eick, 2002; Mulholland & Wallace, 2001; Tabachnick & Zeichner, 1999). For example, Eick found that the 2 early-career middle school teachers in the study used hands-on activities less often over time because of concerns about discipline. In sum, based on the few studies we identified in this area, we see that new teachers tend to have concerns about and struggles with management, sometimes leading them to engage in less reform-oriented teaching practices.

Effective Science Learning Environments

Several studies looked at teachers' ideas and practices with regard to creating effective science learning environments beyond developing structures for classroom management (Hayes, 2002; Loughran, 1994; Luft et al., 1999; McDevitt et al., 1993; Peterson & Treagust, 1998; Powell, 1997; Sillman & Dana, 2001; Simmons et al., 1999). Some of these looked at how student-centered the learning environments were. For example, the 4 preservice elementary teachers in Sillman and Dana's study came to care about whether "learners felt free to take risks and learn" (p. 98) and in their practice would compromise their other beliefs to make sure the environment was safe. A study by Simmons and colleagues indicates that some surprising shifts may take place over time; 69 early-career secondary teachers participated in the study and the first- and second-year teachers demonstrated more student-centered teaching styles (defined broadly) than did the third-year teachers. These studies highlight the importance that the teachers placed on developing learning environments that were centered around students—but also the struggles they faced in creating and maintaining those environments, as did the teachers described earlier who used hands-on activities less often over time because of concerns about management.

Summary and Commentary for Theme 4

The few studies that described the role of classroom management in new science teachers' learning environments indicated that concerns about management made teachers unlikely to engage in reform-oriented science teaching practices.

Most of the other studies we reviewed within this theme addressed how student-centered a learning environment was, and seemed to take student-centered instruction as a gold standard that teachers should strive to achieve. Different researchers, however, hold different ideas about what "student-centered" and other similar phrases mean. For example, some researchers use "student-centered" as a synonym for "constructivist" or to refer to teaching by building on students' ideas. Others use the term to indicate that the students' interests drive the teacher's curricular choices. Still others use it to indicate that learners feel free to take risks. In these studies, differences in usage would manifest themselves as differences in desirability. (We, for example, would argue that expecting new science teachers to engage primarily in instruction where students decide on topics to explore and experiments to conduct may be setting the teachers up to fail. Given that inquiry-oriented instruction can fall along a continuum of more to less student-directed (NRC, 2000), perhaps new teachers should engage in more teacher-directed yet still inquiry-oriented instruction until they overcome some of the other challenges they face.) Achieving greater clarity with regard to all of these terms would foster more productive exchange of ideas among researchers.

Furthermore, we found little literature focused on how new science teachers foster collaboration among their students or develop learning environments conducive to inquiry-oriented science—yet these are emphasized by the standards. We see these as areas in which further research would be fruitful, to help the field identify what aspects of these practices are especially challenging for new teachers.

Theme 5: Challenges Related to Understanding Professionalism

The final theme, *professionalism*—or becoming a professional—emphasizes being "a reflective practitioner who continually evaluates the effects of his/her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally" (INTASC, 1992, p. 31). The teacher should develop relationships with all of his or her constituencies, including colleagues and parents, and should understand the school as it exists within the larger community context (INTASC, 1992). Being a professional also involves planning and developing the school's science program and participating in relevant professional development experiences (NRC, 1996). The studies reviewed within this theme, then, attend to a final challenge, asking, How do new science teachers view their roles as professional teachers, and what factors promote and constrain their development as a professionals?

We present 30 studies for Theme 5 (see Table 2). Approximately two-thirds of the studies involved elementary teachers and about three-quarters involved preservice teachers. These papers included studies about becoming a part of the community and a reflective practitioner and developing an identity and self-efficacy (a perception of one's effectiveness) as a science teacher. The latter issues, regarding identity and self-efficacy, are not explicit in the standards but are implied by the phrase "becoming a professional," so we include them here. On the other hand, although participating in professional development is important according to the standards, we found too little research here to include it as a separate section in our review. Overall, these studies highlight the importance of collegial support, reflection, role identity, and self-efficacy in becoming a science teacher. The review also identifies limitations in the research base in relation to some of these factors.

Becoming a Part of the Community

A few papers described the important role that both novice and experienced colleagues could play in helping new teachers to become professionals (Appleton & Kindt, 2002; Colburn & Tillotson, 1998; Eick, 2002; Loughran, 1994). For example, a study of 9 early-career elementary teachers found that teachers with supportive colleagues were more likely to enact challenging or risky activities (Appleton & Kindt, 2002). A study of 2 early-career middle school teachers found that they watched each other teach, supported and learned from one another, and felt that they could confide in each other but not in their other colleagues (Eick, 2002).

New teachers also need to learn about schools to become a part of the school community (Appleton & Kindt, 2002; Colburn & Tillotson, 1998; Howes, 2002). Appleton and Kindt (2002) identify three important aspects of knowledge of schools: understanding the priority of science in a school culture, understanding the degree of personal choice one has about the curriculum, and identifying and obtaining resources for science teaching. We described in Theme 3 how these factors played out in leading teachers to engage in less innovative teaching strategies or even to avoid teaching science altogether. We found only one paper that had to do with a fourth important factor: interactions with parents. The preservice secondary teachers in the study struggled with how to deal with a concerned parent (Colburn & Tillotson, 1998).

Becoming a Reflective Practitioner

Several studies looked at the importance of engaging in reflection (Arellano et al., 2001; Bryan & Abell, 1999; Crawford, 1999; Gunstone, Slatterly, Baird, & Northfield, 1993; Sillman & Dana, 2001; Sweeney et al., 2001; Tabachnick & Zeichner, 1999). All but one of these studies focus on preservice teachers, and in fact that study (Sweeney et al., 2001) describes only one early-career teacher. That said, it seems that considering cases can promote critical reflection (Arellano et al., 2001). Reflecting can help teachers to talk about learning and teaching (Sillman & Dana, 2001), identify inconsistencies between their beliefs and practices (Bryan & Abell, 1999; Sweeney et al., 2001), and engage in inquiry-oriented science teaching (Crawford, 1999). Furthermore, the extent of change in the beliefs and knowledge of 13 preservice secondary teachers was dependent, in part, on how reflective they were (Gunstone et al., 1993).

One study explored the focus of a single preservice secondary teacher's reflection over the course of his year in a teacher education program (Geddis & Roberts, 1998). Even by the end of his program, he focused on issues highlighted as challenges across the previous sections of this review, such as classroom management, teaching subject matter, the perceived shortcomings of students, and identifying connections between theory and practice.

These studies provide evidence that reflection is, indeed, important in becoming a professional and can help new teachers to develop their knowledge and practice.

Even reflection, though, does not guarantee the development or even consideration of sophisticated ideas.

The Development of Identity

Envisioning oneself as a science teacher is critical in becoming a professional. Several studies investigated new teachers' identities as teachers (Adams & Krockover, 1997a; Appleton & Kindt, 2002; Eick & Reed, 2002; LaTurner, 2002; Meadows & Koballa, 1993; Sweeney et al., 2001). The 40 preservice elementary teachers in a study by Meadows and Koballa tended to identify themselves as future teachers of all subject areas, not specifically as science teachers. This factor contributed to their disinclination to join the National Science Teachers Association, a professional organization. Factors such as aspects of one's personal history influence one's identity development (Adams & Krockover, 1997a; Eick & Reed, 2002; LaTurner, 2002; Sweeney et al., 2001). For example, 2 of the 4 early-career secondary teachers in Adams and Krockover's study relied heavily on personal experiences (e.g., teaching horseback riding), and 2 found it helpful to have served as a teaching assistant in a college-level science class. Teachers' identity development is also influenced by their experiences as teachers in schools and classrooms (Appleton & Kindt, 2002); and the reverse is also true (Eick & Reed, 2002; Hayes, 2002). For example, in Eick and Reed's study, the 12 preservice secondary teachers with stronger abilities to envision themselves as teachers benefited more from their teacher education experiences and were better teachers of inquiry-oriented science. In sum, one's personal history affects one's identity, which in turn affects one's development as a teacher.

Self-Efficacy

In addition to coming to see themselves as science teachers, individuals must develop confidence in themselves and come to see themselves as effective practitioners in the classroom. Most of the studies in this section take as a premise that developing self-efficacy (a sense of oneself as effective) is a challenge that new science teachers face. One study—the only study in this group involving secondary teachers—found that second-year secondary teachers felt more confident than they had in their first year of teaching (Loughran, 1994). Several studies describe relationships between self-efficacy and other factors (Appleton & Kindt, 2002; Czerniak & Shriver, 1994; Enochs et al., 1995; Ginns & Watters, 1999; Loughran, 1994). Teachers with higher self-efficacy engage students in more student-centered lessons (Loughran, 1994), believe that students are capable of learning through cooperation and experience (Enochs et al., 1995), and develop more as science teachers (Appleton & Kindt, 2002). In addition, a study of 49 preservice elementary teachers found that teachers with high self-efficacy typically focused attention on children, wanted children to become autonomous learners, chose activities to promote learning, used educational theories from classes, and held beliefs about science consistent with the reform documents. Low self-efficacy teachers, on the other hand, frequently blamed others for their failures, chose activities because they were fun, and focused on student behavior rather than student learning (Czerniak & Shriver, 1994). Another study, however, looked at 3 early-career elementary teachers and found that even those with low self-efficacy were able to create quality science programs for their students; the authors concluded that self-efficacy beliefs do not account fully for a new teacher's decision making (Ginns & Watters, 1999).

One study explored the relationships between self-efficacy and common alternative ideas about science content (Schoon & Boon, 1998). In this study of 619 preservice elementary teachers, the authors identified a few "critical conceptions" (p. 565) that were related to low self-efficacy: The teachers who held certain inaccurate beliefs (e.g., that electricity is used up in appliances; that dinosaurs and humans coexisted) also tended to have low self-efficacy. The authors hypothesize that these non-normative ideas may make it difficult to understand other science topics and thus may serve as one of the many causes of low self-efficacy.

Several other studies—all involving elementary teachers—identify a variety of factors that are correlated with self-efficacy and possibly influence its growth (Cannon & Scharmann, 1996; Enochs et al., 1995; Ginns & Watters, 1999; Huinker & Madison, 1997; King & Wiseman, 2001; Mulholland & Wallace, 2001; Scharmann & Hampton, 1995; Wilson, 1996). The study by Enochs and colleagues involving 73 preservice elementary teachers found a significant correlation between self-efficacy and number of science courses taken. Other studies identify higher self-efficacy as being related to methods classes (Ellis, 2001; Huinker & Madison, 1997; King & Wiseman, 2001; Scharmann & Hampton, 1995) and field experiences (Cannon & Scharmann, 1996; Huinker & Madison, 1997; Wilson, 1996). However, emphasizing interdisciplinary instruction and using different types of cooperative learning groups in methods classes were not related to differences in teachers' self-efficacy (King & Wiseman, 2001; Scharmann & Hampton, 1995). Wilson, in a study of 18 preservice elementary teachers (a subset of the total of 26), unpacked some of the factors relevant to self-efficacy and field experiences; for example, participating in teams of 2 or 3 in the field was related to significant improvements in the teachers' self-efficacy scores.

Though most studies of self-efficacy presume that higher self-efficacy is better, one study of approximately four hundred preservice elementary teachers in a new teacher education program emphasizing elementary science teaching found that the teachers who completed the program actually felt less prepared to teach science than had participants in the old program (Boone & Gabel, 1998). The authors hypothesize that the participants had developed more realistic conceptions of what elementary science teaching involved.

Summary and Commentary for Theme 5

The studies reported in Theme 5 involve larger numbers of participants, overall, than for the studies Themes 2, 3, and 4; only Theme 1 had a larger mean and median number of participants (see Table 2). Few papers focused squarely on the importance of colleagues and reflection, both of which are well-represented in the general teacher education literature. The existing studies showed the importance of having supportive colleagues and engaging in reflection. Finding supportive colleagues and developing a reflective disposition may both be counted as challenges that new teachers face. We wonder, however, what reflection by new science teachers looks like outside the context of teacher education courses and research studies; little is known about typical early-career science teachers' reflection (and, in fact, only one study involved an early-career teacher at all). Furthermore, little is known about what teachers in general reflect on, or about whether different focuses for reflection (e.g., learners, inquiry) are differentially helpful (see Davis, 2006), or whether different modes of reflection (e.g., written, oral) are more effective for different individuals.

We found that personal characteristics—such as reflectiveness, identity, personal history, and self-efficacy—matter a great deal. Yet there is relatively little research on how some of these characteristics *develop* or how they *interact* with other factors investigated across the five themes of this review. We also found relatively little research that measured even a snapshot of some of these factors for some groups, such as secondary teachers' self-efficacy, despite the challenges for new teachers that cut across grade-level.

One additional issue not addressed by the standards is time management. Two studies describe the challenges for new science teachers in accomplishing everything they need to accomplish (Adams & Krockover, 1997b; Loughran, 1994). Given the stresses that they face and the time it can take even to obtain the necessary resources for inquiry-oriented science teaching, much less to plan and enact it, the standards documents may be remiss in not explicitly pointing to the importance of developing time-management skills.

Our analysis indicates that the field needs more research on how new science teachers learn about their schools and communities. Some issues here would be subject-general, while others would be specific to science. For example, how do new science teachers learn about the norms in their schools regarding how teachers use (or do not use) standards documents? How do they learn about parental expectations in terms of religion and science, or teaching-to-the-test, or any of the many other things that can catch new teachers off guard?

Finally, the field needs more information about new teachers' experiences with, and opportunities for, professional development. Though professional development is included in the standards as an expectation for effective science teachers, few papers describe what it entails for new teachers or examine the challenges that they face in finding or participating in professional development.

Supports

Having reviewed the challenges that new science teachers face, we turn now to ways that teacher educators can support them in overcoming those challenges, reiterating our argument that preservice and inservice teacher education must become more effective and efficient to meet the demand for highly qualified science teachers. The supports provided for teachers must be aligned with their actual needs. In this section we discuss a range of possible supports and expand on a few that provide evidence of success in addressing the challenges we identified. We present examples of supports in three areas—science coursework, preservice teacher education programs, and induction and professional development programs—followed by a set of supports that cut across context. Our review here is intended to be suggestive rather than exhaustive. Other useful reviews that focus more directly on supports for teacher learning complement and extend our brief treatment here (e.g., Anderson & Mitchener, 1994; Fishman & Davis, 2006; Grossman, 2005; Marx et al., 1998; Wilson & Berne, 1999).

Supportive Science Coursework

We read again and again that simply requiring more science content courses is not enough to enable teachers to develop improved understanding of science content and inquiry and the nature of science (e.g., Gess-Newsome & Lederman, 1993; Lawson, 2002; Rubba & Harkness, 1993; Stofflett & Stoddart, 1994; see also Floden & Meniketti, 2005). But some studies do point to ways in which science teachers' subject matter knowledge might be improved through coursework quite different from the typical fare offered by schools of education and university science departments.

For example, one line of research investigated the ways in which a conceptual change unit could promote productive changes in preservice elementary teachers' understandings of topics having to do with the water cycle (Stoddart et al., 1993; Stofflett & Stoddart, 1994). The 3-week unit that these authors used involved eliciting the preservice teachers' preconceptions, guiding their exploration of phenomena, discussing the ideas to try to promote more scientific explanations, comparing new ideas to original ideas, and applying new ideas to real-world situations (Stoddart et al., 1993). Engaging in the unit promoted the development of significantly improved conceptual understandings (Stoddart et al., 1993) and increased the likelihood that teachers would use more reform-oriented instructional practices (Stofflett & Stoddart, 1994). Many science teacher educators assume that teachers should engage in reform-oriented practices as learners if they are to learn more inquiry-oriented teaching practices and become more knowledgeable about the science content, scientific inquiry, and the nature of science; these papers and others (e.g., Atwood & Atwood, 1997; Melear, Goodlaxson, Warne, & Hickock, 2000; Trundle et al., 2002) provide evidence supporting this assumption.

Supportive Preservice Teacher Education

Positive early experiences in teacher education seem to help new science teachers on their road to becoming effective science teachers. Thus considering teacher education programs and specific experiences within them is particularly important. We found examples of teacher education programs with many different emphases, including understanding equity, modeling effective instruction, and even teaching elementary science. Not surprisingly, the focused programs tend to be effective at promoting change in the area in which they are focused.

Science methods courses and teacher education programs can, of course, help to promote improved understanding of instruction (e.g., Adams & Krockover, 1997a; Akerson & Flanigan, 2000; Gunstone et al., 1993; Marion, Hewson, Tabachnick, & Blomker, 1999; McDevitt et al., 1993, 1995; McDevitt, Gardner, Shaklee, Bertholf, & Troyer, 1999; McGinnis et al., 2002; Naylor & Keogh, 1999; Rodriguez, 1998; Roth & Tobin, 2001; Roth, Masciotra, & Boyd, 1999; Roth et al., 2002; Stofflett, 1994; Van Zee & Roberts, 2001; Van Zee, 1998; Zembal-Saul et al., 2000, 2002; Zuckerman, 1999). Zembal-Saul and her colleagues (2000) describe the importance of engaging preservice elementary teachers in multiple cycles of planning, teaching, and reflection, over the course of a year. The preservice teachers who participated in the program emphasizing elementary science teaching improved in how they organized instruction around important scientific ideas (a challenge we identified for elementary teachers, who tended instead to focus on activities) and came to recognize the importance of accounting for their learners as they planned instruction. Another very different form of systematic support that extends beyond the methods class is co-teaching, in which preservice teachers teach and reflect on their teaching with learning communities, including other student teachers, practicing teachers, methods instructors, and students from the classroom (e.g., Roth & Tobin, 2001; Roth et al., 1999, 2002; Tobin, Roth, & Zimmermann, 2001). Participating in co-teaching groups appears to help preservice teachers learn to put their knowledge and beliefs into practice, addressing the challenge of the mismatch between teachers' ideas about instruction and their practices.

Science methods courses and teacher education programs also help preservice teachers to develop improved understandings of and attitudes toward science (e.g., Hynd et al., 1997; Palmer, 2002; Strawitz, 1993), learners (e.g., McDevitt et al., 1995; Rodriguez, 1998; Yerrick & Hoving, 2003), diverse learners and science for all (e.g., Bailey, Scantlebury, & Johnson, 1999; Bullock, 1997; Fraser-Abder, 2001; Richmond et al., 1998; Rodriguez, 1998), and learning environments (e.g., Adams & Krockover, 1997a), as well as promoting self-efficacy (Huinker & Madison, 1997; King & Wiseman, 2001). Science teacher educators recommend innovations as wide-ranging as drawing science concept cartoons (Naylor & Keogh, 1999), writing about one's science learning experiences (Van Zee & Roberts, 2001), and listening to experienced science supervisors' stories about new teachers (Zuckerman, 1999). One study characterized ways in which an elementary science methods instructor's actions contributed to the preservice teachers' self-confidence (Rice & Roychoudhury, 2003). Positive attributes included sharing content and pedagogical knowledge, modeling effective science teaching strategies, creating a respectful environment, and modeling enthusiasm for science and science teaching.

Field experiences also help preservice teachers to overcome certain challenges (e.g., BouJaoude, 2000; Cannon & Scharmann, 1996; Eick, Ware, & Williams, 2003; Ferry, 1993; Huinker & Madison, 1997; Scantlebury & Kahle, 1993; Shey & Baird, 1993). For example, in a study of 120 preservice elementary teachers, the subset of the teachers who had already participated in their field experiences scored significantly higher on a test of self-efficacy than did those who had not yet had experience in the field (Cannon & Scharmann, 1996). The crucial importance of placing preservice teachers in classrooms before their student teaching experiences is highlighted by this and other studies. Following this sequence helps preservice teachers to develop more sophisticated ideas about science instruction and acquire self-efficacy as science teachers.

Supportive Induction and Professional Development Programs

Very few studies of the challenges that early-career science teachers face describe induction programs or professional development programs as ways of overcoming those challenges—in keeping with the overall dearth of studies of early-career teachers. One study, however, provides some evidence that science-specific induction programs can help these teachers. A science-specific induction program helped the teachers to develop more productive learning environments, while teachers without any induction program experienced more problems with classroom management (Luft et al., 2003). Additional studies to replicate or extend this study would further knowledge in this area.

Professional development, too, can help early-career science teachers—perhaps especially in terms of understanding content and instruction. One study looked closely at how and what an early-career elementary teacher learned from a long-term professional development experience in which teachers met to discuss their teaching and engage in science experiments. The teacher under study acquired scientific content knowledge and learned about how scientific knowledge is constructed, and her practice improved (Rosebery & Puttick, 1998). This study provides further evidence that engaging new teachers in effective science teaching while they are still students may help them to develop the knowledge and abilities they need to become effective teachers.

Other Forms of Support

Science teacher educators widely recognize the importance of engaging new teachers in reflection and reflective activities such as action research. Doing so helps new teachers to develop their understanding of learners (e.g., Tabachnick & Zeichner, 1999), instruction (e.g., Adams & Krockover, 1999; Crawford, 1999), learning environments (e.g., Tabachnick & Zeichner, 1999), and professionalism (e.g., Arellano et al., 2001; Bryan & Abell, 1999; Crawford, 1999; Gunstone et al., 1993; Sillman & Dana, 2001; Sweeney et al., 2001; Tabachnick & Zeichner, 1999). Engaging in scientific research also promotes positive effects, particularly in challenges related to understanding science content, inquiry, and the nature of science (e.g., Raphael, Tobias, & Greenberg, 1999) and developing self-efficacy (e.g., Weld & French, 2001).

Establishing collegial relationships—with other new teachers, cooperating teachers, more experienced fellow teachers, or even researchers—also seems important. Doing so helps new teachers to develop improved understandings of instruction (Crawford, 1999; Tobin & LaMaster, 1995; Zembal-Saul et al., 2002) and learning environments (Eick, 2002; Loughran, 1994; Luft et al., 1999). By definition, establishing collegial relationships also helps new teachers to become professionals (e.g., Appleton & Kindt, 2002; Loughran, 1994; Eick, 2002).

Educative curriculum materials (Ball & Cohen, 1996; Collopy, 2003; Davis & Krajcik, 2005; Petish, 2004; Schneider & Krajcik, 2002) and online supports (e.g., Barab et al., 2001; Davis, Smithey, & Petish, 2004; Derry & Hmelo-Silver, 2002; Fishman, 2003; Schlager, Fusco, & Schank, 2002) have potential for supporting new science teachers in overcoming many challenges but have not yet been investigated extensively. A decade ago, Ball and Cohen called for consideration of the role of educative curriculum materials in promoting teachers' learning, because curriculum materials are inherently situated in teachers' practice. Given new teachers' reliance on curriculum materials (Southerland & Gess-Newsome, 1999), their use of educative curriculum materials seems a ripe area for research. Likewise, though there exist many online environments supporting teachers, few are aimed specifically at new teachers. As younger members of society gain technological expertise, supporting them online seems a natural step.

Final Thoughts

We close with a few words about next steps. We pointed to specific areas of future research in our commentaries. For example, the standards emphasize inquiry-oriented science teaching, yet our review of the literature tells us very little about new teachers' understandings of inquiry, how they teach inquiry, or what specific challenges they face in doing so.

More generally, future research should determine how similar the challenges are across content areas. What are the major challenges for new teachers of mathematics? Are they related to the challenges faced by new English or history teachers? How do these relate to challenges identified in studies that do not differentiate by subject area? As Grossman, Wineburg, and Woolworth (2001) remind us, subject matter necessarily shapes how teachers approach the tasks of teaching. Though many of the challenges for new teachers will be similar across subject areas, some will not. Investigating the similarities and differences may be especially important as teacher educators consider how to support new elementary teachers who teach multiple subjects. In addition, we wonder which challenges faced by new science teachers are also faced by experienced teachers trying to teach in new ways. For example, now that inquiry-oriented science teaching is increasingly emphasized by schools, districts, and states, researchers will need to understand the challenges that experienced teachers face as they begin to use that approach.

In our review, the mean number of participants was approximately 75, but the median was only 15 (see Table 2). Larger-scale and replication studies could complement and extend the smaller studies (see Wilson, Floden, & Ferrini-Mundy, 2002, for a discussion of this issue). Furthermore, only a few of the studies that we reviewed looked at early-career teachers (18% included them as participants, and only 13% focused on them exclusively); yet early-career teachers may differ from preservice teachers in important ways, and certainly different questions can be asked about them. Conducting more longitudinal studies would help. Furthermore, studying only preservice teachers in schools of education will necessarily exclude those teachers who come to teaching through alternative paths. Researchers should also try to unpack differences among individuals rather than assuming homogeneous participants.

Finally, with regard to investigations of supports, we encourage researchers to measure multiple outcomes, to characterize how a form of support helps (or fails to help) teachers. For example, if preservice teachers participate in a teacher education program emphasizing the nature of science, one hopes that they will develop improved understandings of and practices related to the nature of science. But what of their understandings of learners, or of classroom management?

As we said at the outset, it will always be hard to be a new teacher. The expectations for new science teachers set by the standards are extremely high, and a new teacher is unlikely to attain them all. Furthermore, not every challenge that a new teacher faces can be ameliorated by teacher education, induction programs, professional development, or other supports. Indeed, some challenges need to be addressed at the institutional or policy level. Preservice and inservice teacher educators may, however, be better able to help new teachers if they map the supports they provide onto the challenges the new teachers face. This review, by cataloguing the challenges, is intended to assist in that design process.

Notes

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[1]*Humanics* is the study of human nature. In the view of learning as humanics, teaching and learning are regarded as being "personal and very human activities" (Gurney, p. 578).

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APPENDIX A

Summary of INTASC science teaching standards

1. *Content:* The teacher of science understands the central ideas, tools of inquiry, applications, and structure of science and of the science disciplines that he or she teaches and can create learning activities that make these aspects of content meaningful to students. (p. 2)
2. *Student Learning and Development:* The teacher of science understands how students learn and develop and can provide learning opportunities that support students' intellectual, social, and personal development. (p. 3)
3. *Student Diversity:* The teacher of science understands how students differ in their approaches to learning and creates instructional opportunities that are adapted to diverse learners. (p. 4)
4. *Instructional Variety:* The teacher of science understands and uses a variety of instructional strategies to encourage students' development of critical thinking, problem solving, and performance skills. (p. 4)
5. *Learning Environment:* The teacher of science uses an understanding of individual and group motivation and behavior to create a learning environment that encourages positive social interaction, active engagement in learning, and self-motivation. (p. 4)
6. *Communication:* The teacher of science uses knowledge of effective verbal, nonverbal, and media communication techniques to foster active inquiry, collaboration, and supportive interaction in the classroom. (p. 6)
7. *Curriculum Decisions:* The teacher of science plans instruction based on knowledge of subject matter, students, the community, and curriculum goals. (p. 6)
8. *Assessment:* The teacher of science understands and uses formal and informal assessment strategies to evaluate and ensure the continuous intellectual, social, and physical development of the student. (p. 6)
9. *Reflective Practitioners:* The teacher of science is a reflective practitioner who continually evaluates the effects of his or her choices and actions on others (students, parents, and other professionals in the learning community) and who actively seeks out opportunities to grow professionally. (p. 7)
10. *Community Membership:* The teacher of science fosters relationships with school colleagues, parents, and agencies in the larger community to support students' learning and well-being. (p. 8)

Note. The information is quoted or paraphrased from Interstate New Teacher Assessment and Support Consortium (INTASC), Science Standards Drafting Committee, 2002.

APPENDIX B

Summary of NSES science teaching standards

A. Teachers of science plan an inquiry-based science program for their students. (p. 30)
B. Teachers of science guide and facilitate learning. (p. 32)
C. Teachers of science engage in ongoing assessment of their teaching and of student learning. (pp. 37–38)
D. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. (p. 43)
E. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. (pp. 45–46)
F. Teachers of science actively participate in the ongoing planning and development of the school science program. (p. 51)

Note. From National Research Council, *National Science Education Standards* (NSES), 1996.

APPENDIX C
Studies cited in review of challenges

Study	*n* (Participants)	Grade level	Preservice or early career teachers	*n* (Additional participants)
Abd-El-Khalick & Lederman, 2000	15	Secondary	Preservice	166
Abd-El-Khalick, 2001	30	Elementary	Preservice	
Abell & Roth, 1994	1	Elementary	Preservice	
Abell et al., 1998	49	Elementary	Preservice	
Adams & Krockover, 1997a	4	Secondary	Early career	
Adams & Krockover, 1997b	11	Secondary	Early career	
Akerson et al., 2000	50	Elementary	Preservice	
Anderson et al., 2000	3	Elementary	Preservice	
Appleton & Kindt, 2002	9	Elementary	Early career	
Arellano et al., 2001	6	Elementary	Preservice	
Atwood & Atwood, 1996	49	Elementary	Preservice	
Atwood & Atwood, 1997	51	Elementary	Preservice	
Bell et al., 2000	13	Secondary	Preservice	
Bendall et al., 1993	20	Elementary	Preservice	10
Bianchini & Solomon, 2003	6	Secondary	Both	2
Bianchini et al., 2003	3	Secondary	Early career	
Boone & Gabel, 1998	400	Elementary	Preservice	
Bradford & Dana, 1996	1	Secondary	Early career	
Bryan & Abell, 1999	1	Elementary	Preservice	
Bullock, 1997	6	Secondary	Preservice	
Cannon & Scharmann, 1996	120	Elementary	Preservice	
Carlsen, 1993	4	Secondary	Preservice	
Cobern & Loving, 2002	700	Elementary	Preservice	
Colburn & Tillotson, 1998	n/a	Secondary	Preservice	
Crawford, 1999	1	Secondary	Preservice	
Czerniak & Shriver, 1994	49	Elementary	Preservice	
Donahue, 2000	10	Secondary	Preservice	
Ebenezer, 1996	4	Elementary	Preservice	
Edwards & Ogden, 1998	15	Elementary	Preservice	
Eick & Reed, 2002	12	Secondary	Preservice	
Eick, 2002	2	Secondary	Early career	
Ellis, 2001	62	Elementary	Preservice	
Enochs et al., 1995	73	Elementary	Preservice	
Geddis & Roberts, 1998	1	Secondary	Preservice	
Geddis et al., 1993	2	Secondary	Preservice	
Gess-Newsome & Lederman, 1993	10	Secondary	Preservice	
Ginns & Watters, 1995	321	Elementary	Preservice	
Ginns & Watters, 1999	3	Elementary	Early career	
Guillaume, 1995	20	Elementary	Preservice	
Gunstone et al., 1993	13	Secondary	Preservice	
Gurney, 1995	151	Secondary	Preservice	
Haidar, 1997	173	Secondary	Preservice	
Hammrich, 1997	15	Elementary	Preservice	

(continued)

Study	*n* (Participants)	Grade level	Preservice or early career teachers	*n* (Additional participants)
Haney & McArthur, 2002	4	Secondary	Preservice	
Hayes, 2002	22	Elementary	Preservice	
Howes, 2002	4	Elementary	Preservice	13
Huinker & Madison, 1997	62	Elementary	Preservice	
Hynd et al., 1997	73	Elementary	Preservice	
Kamen, 1996	1	Elementary	Early career	
King & Wiseman, 2001	120	Elementary	Preservice	
Koballa et al., 1999	9	Secondary	Preservice	
LaTurner, 2002	211	Secondary	Early career	
Lawrenz & Gray, 1995	48	Secondary	Preservice	
Lawson, 2002	22	Secondary	Preservice	
Lederman & Latz, 1995	12	Secondary	Preservice	
Lederman et al., 1994	12	Secondary	Preservice	
Lee, 1993	1486	Elementary	Preservice	
Lemberger et al., 1999	3	Secondary	Preservice	
Lin & Chen, 2002	63	Secondary	Preservice	
Lord & Holland, 1997	250	Secondary	Preservice	
Loughran, 1994	14	Secondary	Early career	
Luft et al., 1999	1	Secondary	Preservice	
Luft et al., 2003	18	Secondary	Early career	
Lynch, 1997	25	Secondary	Both	
McDevitt et al., 1993	246	Elementary	Preservice	
McDevitt et al., 1995	n/a	Elementary	Preservice	
Meadows & Koballa, 1993	40	Elementary	Preservice	
Mellado, 1998	4	Both	Preservice	
Meyer et al., 1999	3	Elementary	Preservice	
Mulholland & Wallace, 2001	1	Elementary	Both	
Odom & Settlage, 1996	55	Elementary	Preservice	
Palmquist & Finley, 1997	15	Secondary	Preservice	
Pankratius, 1995	1	Secondary	Preservice	
Peterson & Treagust, 1998	2	Elementary	Preservice	21
Powell, 1994	1	Secondary	Preservice	
Powell, 1997	2	Secondary	Early career	
Rice & Roychoudhury, 2003	52	Elementary	Preservice	
Richmond et al., 1998	(4 classes)	Both	Preservice	
Rodriguez, 1998	18	Secondary	Preservice	
Rosebery & Puttick, 1998	1	Elementary	Early career	
Roth et al., 1998	32	Secondary	Preservice	
Rubba & Harkness, 1993	26	Secondary	Both	19
Scantlebury & Kahle, 1993	7	Secondary	Preservice	
Scharmann & Hampton, 1995	84	Elementary	Preservice	
Schoon & Boon, 1998	619	Elementary	Preservice	
Settlage, 2000	76	Elementary	Preservice	
Shapiro, 1996	1	Elementary	Preservice	
Sillman & Dana, 2001	4	Elementary	Preservice	
Simmons et al., 1999	69	Secondary	Early career	

(*continued*)

Study	*n* (Participants)	Grade level	Preservice or early career teachers	*n* (Additional participants)
Smith & Anderson, 1999	9	Elementary	Preservice	
Smith, 1999	5	Elementary	Preservice	17
Smith, 2000	1	Elementary	Preservice	
Southerland & Gess-Newsome, 1999	22	Elementary	Preservice	
Stoddart et al., 1993	75	Elementary	Preservice	
Stofflett & Stoddart, 1994	27	Elementary	Preservice	
Sullenger et al., 2000	5	Both	Preservice	
Sutton et al., 1993	62	Elementary	Preservice	
Sweeney et al., 2001	1	Secondary	Early career	
Sweeney, 2001	137	Both	Both (includes inservice)	
Tabachnick & Zeichner, 1999	22	Both	Preservice	
Trumper et al., 2000	498	Elementary	Preservice	
Trumper, 2003	645	Elementary	Preservice	
Trundle et al., 2002	78	Elementary	Preservice	
van Driel et al., 2002	12	Secondary	Preservice	
Wilson, 1996	18	Elementary	Preservice	26
Windschitl, 2003	6	Secondary	Preservice	
Yerrick & Hoving, 2003	n/a	Secondary	Preservice	
Yerrick et al., 2003	5	n/a	Preservice	
Young & Kellogg, 1993	96	Elementary	Preservice	179
Zembal-Saul et al., 2000	2	Elementary	Preservice	
Zembal-Saul et al., 2002	3	Elementary	Preservice	
Zuckerman, 2000	36	Secondary	Preservice	

Note. Numbers listed in the far right column indicate how many participants in a study were not relevant for this review (i.e., not preservice or early career elementary or secondary science teachers). n/a = not available.