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This review analyzes and synthesizes current research on science education with ELLs. Science learning outcomes with ELLs are considered in the context of equitable learning opportunities. Then, theoretical perspectives guiding the research studies reviewed here are explained, and the methodological and other criteria for inclusion of these research studies are described. Next, the literature on science education with ELLs is discussed with regard to science learning, science curriculum (including computer technology), science instruction, science assessment, and science teacher education. Science education initiatives, interventions, or programs that have been successful with ELLs are highlighted. The article summarizes the key features (e.g., theoretical perspectives and methodological orientations) and key findings in the literature, and concludes with a proposed research agenda and implications for educational practice.

Keywords: English language learners, science education.

As immigrants come to represent an increasing fraction of the U.S. student population, teachers should address the educational needs of students who are in the process of acquiring the language and culture of the U.S. mainstream while also learning the norms, content, and processes of academic disciplines. Although English language and literacy development in the context of subject area instruction is emphasized for English language learners, or ELLs (Teachers of English to Speakers of Other Languages, 1997), research focuses primarily on English language proficiency, with limited attention to subject area instruction such as science (August & Hakuta, 1997).

There is a pressing need to address student diversity in science classrooms, as knowledge of science and technology is an important part of being an educated citizen in the informational and technological world of the 21st century (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996). Traditionally, the science and science education communities have advocated for greater participation of nonmainstream individuals in science-related fields but have expected these individuals to assimilate to the established institutional culture (Eisenhart, Finkel, & Marion, 1996; Lee, 1999; Rodriguez, 1997). There has been little recognition of the linguistic and cultural resources that nonmainstream individuals and groups bring to the science classroom, and little thought has been given to how to articulate these resources with the norms and practices of science disciplines and school science to enhance student learning (Lee, 2002, 2003; Lee & Fradd, 1998; Rosebery, Warren, & Conant, 1992; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001).

To keep from falling behind their English-speaking peers in academic content areas, such as science, ELLs need to develop English language and literacy skills in the context of subject area instruction. Ideally, subject area instruction should provide a meaningful context for English language and literacy development, while advancing English skills provides the medium for engagement with academic content. As more states adopt immersion approaches to English for Speakers of Other Languages (ESOL) or English as a Second Language (ESL) instruction, ELLs frequently confront the demands of academic learning through a yet-unmastered language. Furthermore, teachers often lack the knowledge and the institutional support needed to address the complex educational needs of ELLs. Thus a vision of reform aimed at academic achievement of ELLs requires integrating knowledge of academic disciplines with knowledge of English language and literacy development. The need for such integration is especially urgent, given the climate of standards-based instruction, high-stakes assessment, and accountability facing today's schools. The literature review presented in this article is a step in developing such an empirically based integration.

This literature review analyzes and synthesizes current research on science education with ELLs. It consists of five sections. First, science learning outcomes with ELLs are considered in the context of equitable learning opportunities. Second, theoretical perspectives guiding the research studies reviewed here are explained. Third, the methodological and other criteria for inclusion of these research studies are described. Fourth, the literature on science education with ELLs is discussed with regard to science learning, science curriculum (including computer technology), science instruction, science assessment, and science teacher education. Science education initiatives, interventions, or programs that have been successful with ELLs are highlighted. The final section summarizes the key features (e.g., theoretical perspectives and methodological orientations) and key findings in the literature, proposes a research agenda to strengthen those areas in which the need for a knowledge base is most urgent as well as those that show promise in establishing a robust knowledge base, and offers implications for educational practice.

Science Learning Outcomes With ELLs

International and national studies on science achievement indicate poor science performance of U.S. students overall and persistent achievement gaps between mainstream and nonmainstream students within the United States (Campbell, Hombo, & Mazzeo, 2000; National Center for Education Statistics, 1996; Schmidt, McKnight, & Raizen, 1997). ELLs were excluded from most large-scale assessments until very recently. The 2000 National Assessment of Educational Progress [NAEP] report card was the first (since the NAEP's inception in 1969) to analyze assessment accommodations in science, but the results did not disaggregate limited English proficient students from students with disabilities (O'Sullivan, Lauko, Grigg, Qian, & Zhang, 2003). This practice "literally creates a kind of systemic 'ignorance' about the educational progress" of ELLs and "leaves the school, district, or system utterly unable to account for the learning of these students" (Lacelle-Peterson & Rivera, 1994, p. 70).

Equitable learning opportunities occur when school science values and respects the experiences that ELLs bring from their home and community environments, articulates their linguistic and cultural knowledge with science disciplines, and offers educational resources and funding to support their learning at levels comparable to those available for mainstream students (Lee, 1999; S. Lynch, 2000). When provided with such opportunities, ELLs can capitalize on their linguistic and cultural experiences as intellectual resources for learning science (Lee, 2002; Warren et al., 2001). Furthermore, equitable learning environments allow ELLs to develop academic proficiencies in English as well as their home language.

Science outcomes include achievement scores on standardized tests, course enrollments, high school completion, higher education, and career choices in science-related fields. Science outcomes also include meaningful learning of classroom tasks, and affect (attitudes, interest, motivation) in science. In addition, desired science outcomes with ELLs include becoming bicultural, bilingual, and biliterate with regard to their home language and culture, on the one hand, and the language and culture of Western science, on the other. Students from all language backgrounds need to acquire the discourse of science as well as the discourse of their homes and communities, to understand the culture of science as well as their own cultures, and to behave competently across social contexts. Furthermore, from a critical theory perspective, desired science outcomes include agency and empowerment, as students become aware of social injustice and inequity—the unequal distribution of social resources and the school's role in the reproduction of social hierarchy—and take actions to address such problems in their communities.

In the current policy context, which stresses structured English immersion for ELLs (without attention to the development of the student's first language) and severely limits subject area instruction in languages other than English, English proficiency becomes a de facto prerequisite for science learning. In this sense, acquisition of oral and written English and exit from ESOL or ESL programs, although they do not constitute "science outcomes" per se, play a large role in determining science outcomes as they are commonly measured.

It must be acknowledged that current educational policies and practices do not generally support desired science outcomes with ELLs. Policies and practices do not consider maintenance and/or development of ELLs' oral and written proficiencies in the home language as relevant to academic achievement, nor do they substantially engage or incorporate the knowledge and practices that ELLs bring to science classrooms. Resources are scarcer and teacher attrition is higher in inner-city schools where ELLs and other nonmainstream students tend to be concentrated. Furthermore, the negative impact of educational policies affecting science education tends to be greater for ELLs. For example, in states requiring accountability in literacy and mathematics but not in science, the pressure for accountability overshadows the concern for ELLs' learning opportunities in science. Science instruction for ELLs is often de-emphasized relative to the urgent task of developing basic skills in literacy and numeracy (Lee, 1999; Lee & Avalos, 2002). Assessment accommodations for ELLs in large-scale science assessments are either not considered or not consistently implemented, resulting in imprecise knowledge about the strengths, needs, and academic progress of these students (Abedi, 2004; Abedi, Hofstetter, & Lord, 2004). Thus educational policies, especially accountability measures, influence educational practices with ELLs more strongly than mainstream students.

Theoretical Perspectives Guiding This Synthesis

This synthesis emphasizes the view that learning is mediated by linguistic, cultural, and social factors. Learning is enhanced—indeed, made possible—when it occurs in contexts that are culturally, linguistically, and cognitively meaningful and relevant to students. If their home languages and cultures are not considered in the educational process, schooling ignores or even negates the tools that students have used to construct their understandings of the world. It is these prior understandings that provide a meaningful context for the construction of new understandings. Thus effective science education incorporates students' prior linguistic and cultural knowledge in relation to science disciplines.

Culture plays an integral role in all students' learning, including that of ELLs. The meanings of the term "culture" have changed across time and across context in anthropology, the subfield of educational anthropology, and other related fields, including bilingual education, multicultural education, cultural psychology, ethnic studies, and cultural studies (Eisenhart, 2001; Gonzalez, 2004). Traditional conceptions of culture viewed it within fixed, static, bounded, and essentialized categories. Current conceptions, however, highlight culture as multifaceted, situated, hybridized, and socially and historically constructed practices (C. Lee, 2003; Eisenhart, 2001; Gonzalez, 2004; Gutierrez & Rogoff, 2003). Furthermore, current conceptions of culture link individual and community-based experiences to broader structural, institutional, discursive, and ideological practices (Orellana & Bowman, 2003).

In the emerging literature on ELLs in science education, researchers have proposed various theoretical underpinnings to guide research and practice. Rather than interpreting issues of science teaching and learning from a particular theoretical perspective, this review considers research originating from multiple theoretical perspectives, including psychological, sociocultural, sociolinguistic, cognitive science, and critical theory. Despite this theoretical variety, the studies covered in this review share the commonality of focusing on the linguistic, cultural, and social contexts of student diversity in science education.

Terminology can be problematic in any review, because different researchers use established terms to mean different things, and some invent their own terms to express novel concepts (or rejection of existing terms). In this article, terms are used as they appeared in the studies in order to represent the original intentions of the researchers, to the extent that this does not confuse or conflate the ways these terms are typically used in the literature. The terms "mainstream" and "nonmainstream" are used with reference to students' racial/ethnic, cultural, linguistic, and socioeconomic backgrounds. "Mainstream" students (i.e., those who are White, middle- or upper-class, and native speakers of standard English) are more likely to enjoy social prestige, institutionalized privilege, and normative power than "nonmainstream" students. The more inclusive terms "diverse student groups" and "students from diverse backgrounds" are used to refer to the entire gamut of students, mainstream and nonmainstream. The terms "first language," "home language," "native language," and "mother tongue" are used interchangeably in this article because their use among the studies reviewed herein is inconsistent. Although the language that many immigrant families use predominantly at home may not actually be their first language, none of the studies considered in this article took such nuances into account.

Method for Literature Review

In selecting research studies for inclusion in this synthesis, a systematic review of the relevant literature was conducted according to the following parameters:

1. Studies with direct relevance to the topic, i.e., those involving ELLs in science education and those addressing the intersection between science education and English language acquisition. To the extent that language and culture are interrelated ("languaculture" according to Agar, 1996), this review includes studies examining cultural beliefs and practices that ELLs bring to the science classroom.
2. Studies published from 1982 through 2004. The landmark for science education reform was the release of the *Science for All Americans* document (American Association for the Advancement of Science, 1989). The period between 1982 and 2004 spans the years leading up to the release of this document (1982–1989) and more than a decade afterward (1990–2004).
3. Studies conducted within the United States and abroad, but limited to those published in English and focusing on settings where English is the main medium of science education.
4. Studies focusing on science education at the elementary and secondary levels, K–12. Studies involving post-secondary or adult learners are not included.
5. Empirical studies from different methodological traditions, including (a) experimental and quasi-experimental studies; (b) correlational studies; (c) surveys; (d) descriptive studies; (e) interpretative, ethnographic, qualitative, or case studies; (f) impact studies of large-scale intervention projects; and (g) demographics or large-scale achievement data.
6. Literature reviews and conceptual pieces.

Within these parameters, the process of gathering studies from the various sources was carried out as follows. First, a search of the ERIC database was conducted using the terms "science education" and "school" combined with the following keywords: "bilingual," "limited English proficient (LEP)," "English language learner (ELL)," "English to Speakers of Other Languages (ESOL)," "English as Second Language (ESL)," "equity," "diversity," "minority," "culture," "language," "multicultural," "at-risk," "race," "immigrant/immigration," and "urban education."

Second, selected journals were reviewed manually, including the journals supported by the American Educational Research Association (*American Educational Research Journal, Educational Researcher, Review of Educational Research,* and *Review of Research in Education*), as well as other well-known journals focusing on science education (*Journal of Research in Science Teaching* and *Science Education*) and bilingual/TESOL education (*TESOL Quarterly* and *Bilingual Research Journal*).

From the sources named above, only peer-reviewed journal articles were included. Among these articles, empirical studies, literature reviews, and conceptual pieces were included. Empirical studies were used to report research results, whereas literature reviews and conceptual pieces were used to frame key issues. Neither practitioner-oriented articles (e.g., teaching suggestions or descriptions of instructional programs, materials, or lesson plans), nor opinion or advocacy pieces unsupported by empirical evidence were included.

Research Synthesis

The literature review produced studies in the following areas: (a) science learning; (b) science curriculum (including computer technology); (c) science instruction; (d) science assessment; and (e) science teacher education. Some studies addressed multiple topics across these areas and thus are included in more than one area. Each study is briefly described within the text, with a focus on the research purpose and results. Other aspects of the studies are presented in the Appendix, including the research setting, participants, focus of intervention, language treatment, data collection, and data analysis.

Science Learning

Studies on science learning are reported with regard to the following topics: (a) cultural beliefs and practices in relation to science learning; (b) scientific reasoning and argumentation; and (c) linguistic influences on science learning. Studies address these topics from multiple theoretical perspectives and use various research methods. Studies on science learning were often conducted in the context of instructional interventions; those studies that specifically focus on student learning are discussed here, whereas those focusing on teaching processes are discussed later in the "Science Instruction" section.

Cultural Beliefs and Practices

A small body of research has examined culturally specific communication and interaction patterns in science learning among nonmainstream students (see the review by Atwater, 1994). Literature reviews have addressed science education among African American (Atwater, 2000; Norman, Ault, Bentz, & Meskimen, 2001), Asian American (Lee, 1996), Hispanic (Rakow & Bermudez, 1993), and Native American students (Kawagley, Norris-Tull, & Norris-Tull, 1998; Nelson-Barber & Estrin, 1995). These reviews indicate that cultural patterns affect science learning within each group and that the patterns are often inconsistent with the expectations of school and school science.

At the start of their programmatic line of research, Science for All, in the early 1990s, Lee and Fradd (1996a, 1996b; Lee, Fradd, & Sutman, 1995) worked with dyads of African American, Haitian, Hispanic, and White elementary students. The students interacted with teachers who were matched in terms of language, culture, and gender (e.g., a dyad of Haitian girls with a Haitian female teacher) while working on science tasks outside the classroom setting. The results indicated similarities and differences among the student groups with regard to science vocabulary, science knowledge, and cognitive strategy use (Lee, Fradd, & Sutman, 1995), written and pictorial representation of science concepts (Lee & Fradd, 1996a), and verbal discourse, nonverbal communication, and engagement in science tasks (Lee & Fradd, 1996b). The results also suggested that the communication and interaction patterns of nonmainstream students were inconsistent with those expected in school and school science.

School science assumes that students have certain prior knowledge with regard to scientific practices. In science classrooms, students are expected to ask questions, carry out investigations, find answers on their own, and formulate explanations in scientific terms. These practices are essential to scientific inquiry but are not equally encouraged in all languages and cultures (Atwater, 1994; Jegede & Okebukola, 1992; McKinley, Waiti, & Bell, 1992; Sutherland & Dennick, 2002). Cultural norms may also prioritize respect for teachers and other adults as authoritative sources of knowledge. Children who are taught to respect the wisdom and authority of their elders may not be encouraged to question received knowledge in ways that are continuous with a Western scientific worldview or school science.

Scientific Reasoning and Argumentation

In contrast to the studies described above, an emerging body of literature argues that the ways of knowing and talking characteristic of children from outside the linguistic and cultural mainstream are generally continuous with those characteristic of scientific communities. Drawing on both a cognitive science perspective and the sociology of science, this research primarily employs discourse analysis of students' oral and written communication as they interact with teachers or peers during scientific inquiry tasks.

Using detailed analyses of the everyday practice and talk of scientists, recent work in the sociology of science defines science and scientific practices more broadly than the traditional definitions that emphasize experimentation and theory-building (Latour & Woolgar, 1986; M. Lynch, 1985). This expanded view considers scientific practices to be embedded within the personal, social, and historical contexts of scientific communities. It also considers the role of imagination, conjecture, "cultivation of the unexpected," beliefs and desires of individual scientists, and construction of variables during the process of investigation rather than control of predetermined variables.

Based on this expanded view of science and on a more flexible and fluid view of children's everyday sense-making, the Chèche Konnen Project, conducted by Rosebery, Warren, and colleagues, has examined the complex, interactive, and complementary relationships between scientific practices and the everyday sense-making of children from diverse languages and cultures (Ballenger, 1997; Rosebery et al., 1992; Warren et al., 2001). Following a programmatic line of research since the late 1980s, the Chèche Konnen team has conducted case studies of low-income students from African American, Haitian, and Latino backgrounds in bilingual and regular classrooms. It highlights the continuity between the forms of reasoning and argumentation characteristic of nonmainstream, low-income students and those characteristic of scientific communities. It also highlights how the students draw upon their everyday knowledge when engaged in scientific inquiry, reasoning, and argumentation. For example, students as young as first grade employed accounts of everyday experiences, not merely as a context for understanding scientific phenomena but also as a perspective through which to infer previously unnoticed aspects of a given phenomenon and to create possibilities for interpreting the phenomenon differently.

Linguistic Influences on Science Learning

A number of studies focus on linguistic influences on the science learning of ELLs in either bilingual or mainstreamed classrooms. Many of these studies have been conducted outside the United States, in other parts of the English-speaking world. The wide range of theoretical and methodological perspectives represented makes it difficult to draw coherent generalizations from this body of work. Nevertheless, most of the studies coincide in finding that students' limited proficiency in English constrains their science achievement when instruction and assessment are undertaken exclusively or predominantly in English. Studies undertaken within the United States did not posit a major instructional role for students' home languages; in contrast, those studies from countries in which language policies allowed for greater presence of other languages in the classroom point to the cognitive and ideological importance of students' home languages in science learning.

Two studies on the science learning of ELLs within the United States, not surprisingly, focused on Spanish speakers. In an interpretive study, Duran, Dugan, and Weffer (1998) studied how Mexican American high school students constructed understandings of biology concepts based on extant linguistic skills in English. As students became more proficient with semiotic tools (e.g., diagrams), they assumed responsibility for constructing meanings, using their own discursive resources, and the teachers withdrew as the sole scientific authority. The results demonstrated the importance of providing language minority students with opportunities to acquire the language of science and other semiotic tools.

In another study conducted within the United States, Torres and Zeidler (2002) used a three-way factorial design to examine the effects of three independent variables (i.e., English language proficiency, scientific reasoning skills, and students' classification as "language learners") on the dependent variable (scientific content knowledge). The results indicated that the "language learner" variable (i.e., Hispanic ELLs or native English speakers) did not have any statistically significant effect, whereas students' level of English language proficiency and their scientific reasoning skills had significant effects, independently and in interaction with each other. The results suggested that combined high levels of English language proficiency and reasoning skills enhanced students' ability to learn scientific content knowledge in English.

Research undertaken in other parts of the English-speaking world has focused on students from a broad range of language communities, both immigrant and indigenous (Rollnick, 2000). The studies reviewed below focused mainly on the role of ELLs' home language in learning science. Some of these studies went beyond examination of students' use of either the home language or English in the classroom to consider the social, cultural, and demographic dynamics of language communities (e.g., Kearsey & Turner, 1999; Tobin & McRobbie, 1996).

Tobin and McRobbie (1996) conducted qualitative research on how ELL Chinese high school students in Australia endeavored to make sense of what happened in a chemistry class conducted in English. The students employed Cantonese in their oral and written discourse and exhibited high levels of effort, commitment to learn, and task orientation both in and out of school. Students' work ethic was consistent with the expectations of the teacher and with typical schooling practices in their home country. Despite the students' efforts to learn chemistry with understanding, they were limited by their difficulties in English. The results suggested that a linguistic hegemony based on the use of English to teach chemistry and assess performance placed these ELLs in a position of potential academic failure. The researchers argue that learning chemistry can be facilitated when ELLs are provided with opportunities to fully employ their native language tools, when science instruction uses the cultural capital of the students, and when the microculture of the classroom fits the macroculture of students' lives outside the classroom.

Kearsey and Turner (1999) examined whether bilingual students had an advantage with regard to acquiring the specialized linguistic register of science because of their broader experience with language learning and linguistic awareness, or whether interference between their two languages, combined with the additional "language load" implied by the scientific register, placed them at a disadvantage for science learning. The researchers evaluated a commonly used science textbook for bilingual and monolingual students in secondary schools in the United Kingdom (UK). The researchers concluded that bilingual students could benefit from a range of curriculum materials supporting linguistic tasks of various levels of difficulty (in contrast to the standardized nature of the UK's National Curriculum). They also noted that the possible additive effects of bilingualism suggest it should be treated as a resource to foster an improved understanding of scientific language in bilingual students.

Cognizant of the widespread perception that students of Asian background (i.e., from the Indian subcontinent) in the UK perform less well than mainstream British children, Curtis and Millar (1988) examined secondary students' knowledge about basic scientific concepts. The study consisted of two groups of students: Asian students from homes where languages other than (or in addition to) English were spoken and British students who were monolingual in English. The Asian students produced more "indecipherable" statements, suggesting that limited fluency in English affected their ability to express themselves clearly on the given task. The native English speakers gave more scientific ideas and applications, indicating their greater familiarity with the language of school science and of everyday situations related to science. Students' length of school attendance in England was also shown to produce some statistically significant differences; unlike the responses of the "short stay" Asian students, the responses of Asian students with 8 or more years of schooling in the UK were virtually indistinguishable from those of the native English speakers. The researchers concluded that the results did not indicate that science is any more difficult for Asian students, except insofar as language problems hinder their learning and/or expression of ideas.

P. P. Lynch and colleagues examined how students' mother tongue and degree of "Westernization" were associated with their understanding of science concepts in a series of studies involving English-speaking students in Tasmania (Australia), Hindi-speaking students in India, and Tagalog- and B'laan-speaking students in the Philippines. Lynch, Chipman, and Pachaury (1985a) found that, in some cases, purely linguistic factors could aid in concept recognition among Hindi-speaking high school students. Lynch, Chipman, and Pachaury (1985b) also found that what the researchers posited as the highest level of cognitive ability (i.e., preference for generalization) of the Hindi-speaking group was significantly lower than that of the English-speaking group. Furthermore, Lynch (1996a, 1996b) argued that (a) "non-intellectualized" languages such as the indigenous languages of the Philippines are not, in their current form, adequate to correctly express scientific concepts (but still have an important educational role to play because of their cultural and ideological importance); and (b) quality science instruction for non-Westernized students necessarily involves reconstruction of students' worldview.

Discussion

The literature indicates that ELLs' science learning is affected by a variety of factors, including their cultural beliefs and practices, cognitive processes underlying scientific inquiry and reasoning, and linguistic processes. With ELLs, the interplay between English and the home language is critical in learning science. Although it seems valid to conclude that all of these factors contribute to ELLs' science learning, it is difficult to specify the role of each, both independently and in interaction with the others, because of the limited literature. In addition, results emerging from different research traditions are sometimes inconsistent or contradictory. This is probably due in part to differences in emphasis, reflecting the conceptual or ideological commitments among researchers. For example, research on cultural beliefs and practices describes discontinuity between the prior linguistic and cultural knowledge of ELLs and the practices of Western science, whereas research on scientific reasoning and argumentation highlights continuity between these students' ways of knowing and talking and those characteristic of scientific practices. Likewise, some research on ELLs indicates additive effects of students' home language (Kearsey & Turner, 1999), whereas other research emphasizes the limitations of indigenous languages for purposes of science learning (e.g., P. P. Lynch, 1996a, 1996b). In general, when instruction is in English, ELLs' science learning is in direct relation to their level of English proficiency.

Science Curriculum

Appropriate instructional materials are essential for effective instruction, but high-quality materials that meet current science education standards are difficult to find and are even less likely to be available in inner-city schools where nonmainstream students are concentrated (National Science Foundation, 1996). In addition to the need for high-quality science curricula for all students, some science educators call for curricula designed for specific student populations, especially those whose languages and cultures are markedly different from those of Western science or school science (National Science Foundation, 1998). Based on observations of 57 randomly selected elementary bilingual/bicultural classrooms serving predominantly Hispanic/Latino students in a large metropolitan area of the southwestern United States, Barba (1993) reported that the students received science instruction using materials that were not relevant to their language and culture.

To ameliorate the lack of linguistically and culturally relevant materials for ELLs, some efforts are being made to develop and/or evaluate science curriculum materials for these students. Hampton and Rodriguez (2001) tested the impact of a commercially available science curriculum (i.e., the Full Option Science Series, FOSS) designed to foster hands-on inquiry science with Spanish-speaking elementary students who were developing second language fluency along with their first language skills. One written assessment, containing three inquiry items and three open-ended response items in the Foods and Nutrition unit, was administered to fifth-grade students. The assessment was available to the students in Spanish or English, and they could respond in the language of their choice. Of the students, 55% chose to respond in Spanish and 45% responded in English. Correct performance ranged from about 33% to 51% across the six items. There was relatively little difference between children who chose to respond in Spanish and those who chose to respond in English.

Fradd, Lee, Sutman, and Saxton (2002) developed and tested materials that integrated scientific inquiry, home language and culture, and English language and literacy development for Hispanic, Haitian Creole, and monolingual English-speaking elementary students of White and African American descent. The units on matter (culminating in the water cycle) and weather were implemented with fourth-grade students at six elementary schools in a large urban school district. At the beginning and end of each unit, students completed a paper-and-pencil test containing multiple-choice, short-answer, and extended written response items. Students from all ethnolinguistic groups showed statistically significant achievement gains in science knowledge and inquiry, respectively.

A few researchers examined the use of interactive, computer-based curriculum materials with ELLs. Buxton (1999) used student-generated computer models as a medium for elementary students to develop meaningful explanations of science content. The study was based on a qualitative analysis of students' engagement in computer modeling in a two-way bilingual classroom. The results indicated that even for primary grade students with limited prior exposure to computers, the use of student-generated computer models in conjunction with the construction of physical models and other hands-on activities provided meaningful opportunities for students to think, act, and talk scientifically.

Dixon (1995) employed a quasi-experimental research design to test the impact of a computer software program on the science content and visualization ability of middle school students. Treatment group students used the computer software program to conjecture about and construct knowledge of reflections and rotations, whereas control group students were presented with the science content using the traditional, teacher-directed, textbook approach. Treatment group students significantly outperformed the control group on all outcome measures. In both groups, there was no statistically significant difference between ELLs and English-proficient students when they experienced the same instructional environment.

Through these interventions using either text-based or computer-based curriculum materials, ELLs learned to engage in scientific discourse (Buxton, 1999), made positive achievement gains in both science knowledge and inquiry (Fradd et al., 2002), made positive science achievement gains in both the home language and English (Hampton & Rodriguez, 2001), performed comparably when they chose to respond either in English or in their home language (Hampton & Rodriguez, 2001), and performed comparably to English proficient students (Dixon, 1995). Although the results are promising, caution is warranted in drawing conclusions based on this limited literature.

Science Instruction

Effective science instruction must consider students' languages and cultures in relation to pedagogical aims. Reviews of literature on effective instruction have focused on nonmainstream student groups in general (Atwater, 1994; Buxton, 1998; Garaway, 1994; Lee, 2002, 2003; Lee & Fradd, 1998; McKinley et al., 1992; Rollnick, 2000), as well as specific groups including African American (Atwater, 2000), Asian American (Lee, 1996), Hispanic (Rakow & Bermudez, 1993), and Native American students (Nelson-Barber & Estrin, 1995).

Since learning and instruction are closely related, these two areas of literature are guided by common theoretical perspectives. Some studies address science instruction in relation to students' beliefs and practices from a cultural perspective, others address science instruction in relation to students' reasoning and argumentation from a cognitive science perspective, and still others address linguistic processes in science instruction. Within each perspective, some studies examine existing instructional practices, whereas others report on the design and implementation of instructional interventions and their impact on teachers (teaching) and students (learning).

Culturally Congruent Science Instruction

Children from nonmainstream backgrounds acquire in their homes and communities cultural norms and practices that are sometimes incongruent with those of school. Teachers therefore need to be aware of a variety of linguistic and cultural experiences to understand how different students may approach science learning. Unfortunately, science instruction has traditionally relied on cultural examples and artifacts that are often unfamiliar to nonmainstream students (Barba, 1993). Teachers also have difficulties in articulating students' home language and culture with scientific knowledge and discourse.

Westby, Dezale, Fradd, and Lee (1999) worked with Spanish-speaking and Haitian Creole-speaking elementary teachers who shared similar linguistic and cultural backgrounds of their students. The teachers and students engaged in culturally congruent interaction patterns during science classes. For example, the three Hispanic teachers used social talk to relate personal experiences to the academic content, communicated a sense of concern for the well-being of the children, and made humorous comments that appeared to create a positive learning atmosphere conducive to student participation. The Haitian American students were much less familiar with working collaboratively in small groups and received more direct and explicit guidance from the teacher. In addition to establishing culturally congruent interaction patterns, teachers need sufficient knowledge of science to teach effectively. These results, although seemingly obvious, highlight the limitation of the existing literature, which often addresses classroom participants' cultural patterns and disciplinary knowledge of science or other school subjects separately, rather than examining the intersection of the two.

Moje, Collazo, Carillo, and Marx (2001) described a bilingual science teacher of predominantly Spanish-speaking students in an urban middle school in a large school district. Although the teacher had extensive science knowledge and his linguistic and cultural background was similar to that of his students, he often had difficulties in articulating students' everyday knowledge and primary discourse with scientific knowledge and discourse. The results suggest that, to assist students in constructing new knowledge, teachers need to establish spaces in which different discourses and knowledges—from science disciplines, the science classroom, and students' lives—are brought together.

Lee and Fradd have extended the notions of cultural congruence and culturally relevant pedagogy (e.g., Ladson-Billings, 1994, 1995; Osborne, 1996) to propose the framework of "instructional congruence," with the aim of articulating science disciplines with students' languages and cultures (Lee & Fradd, 1998; also Lee, 2002, 2003). This framework highlights the importance of developing *congruence,* not only between students' cultural expectations and norms of classroom interaction but also between students' linguistic and cultural experiences and the specific demands of particular academic disciplines such as science. It emphasizes the role of *instruction,* as teachers explore the relationships among academic disciplines, English language and literacy development, and students' linguistic and cultural knowledge, and devises ways to link these domains. The framework applies not only to teachers but also to any educational intervention, such as curriculum, teacher professional development, or technology application. The need to articulate the three domains in the framework is especially critical when they contain potentially discontinuous elements.

When students' cultural beliefs and practices are discontinuous with those of Western science, effective science instruction should enable students to cross cultural borders between the two domains (Costa, 1995; Jegede & Aikenhead, 1999; Snively & Corsiglia, 2001; also see Giroux, 1992). According to the multicultural education literature, school knowledge represents the "culture of power" of the dominant society (Au, 1998; Delpit, 1988; Reyes, 1992). The rules of classroom discourse are largely implicit and tacit, making it difficult for students who have not learned the rules at home to figure out these rules on their own. For students who are not from the culture of power, teachers need to provide explicit instruction about that culture's rules and norms for classroom behavior. As students gradually acquire the cultural competencies, they may also require explicit instruction on both academic norms and academic content if they are to acquire the high-status knowledge that their more privileged peers have access to outside the classroom. Explicit instruction on academic norms and content in the context of authentic and meaningful tasks and activities has been advocated with nonmainstream students in science instruction (Fradd & Lee, 1999; Lee, 2003).

Based on the notions of instructional congruence and the teacher-explicit to student-exploratory continuum, Lee (2004) worked with six Hispanic elementary teachers (all fluent in English and Spanish) who taught Hispanic students from various racial and national backgrounds in a large urban school district. The research focused on teachers' beliefs and practices with regard to science instruction, incorporation of students' home language and culture in science instruction, and English language and literacy development as part of science instruction. As the teachers continued their participation in the research over the 3-year period, they gradually learned to articulate school science with students' linguistic and cultural experiences, to enable students to take the initiative in conducting scientific inquiry, and to promote English language and literary development of ELLs.

Extending Lee (2004), Lee and colleagues implemented an instructional intervention with more than 1,500 third- and fourth-grade students from six elementary schools serving students from diverse linguistic and cultural backgrounds in a large urban school district. The intervention consisted of instructional units, teacher workshops, and classroom practices to foster instructional congruence and the teacher-explicit to student-exploratory continuum. Lee, Deaktor, Hart, Cuevas, and Enders (in press) examined the intervention's impact on both science and literacy (writing) achievement of all participating students. Cuevas, Lee, Hart, and Deaktor (2005) examined the intervention's impact on the scientific inquiry abilities of a small number of students. Since both studies focused on ELLs, analysis was conducted at different levels of English proficiency. The results indicated that the intervention improved students' science achievement, literacy achievement, and inquiry abilities. In addition, gaps narrowed on several measures of science and literacy among demographic subgroups in terms of gender, ethnicity, socioeconomic status (SES), special education, home language, and English proficiency.

Cognitively Based Science Instruction

The cognitive science perspective sees the relationship between scientific practices and students' sense-making in a complex and reflexive way—as similar, different, interactive, and generative (Brown, 1992; Lehrer & Schauble, 2000). The entry point for effective teaching is to examine the everyday experiences and informal language practices that individual students bring to the learning process. Students have developed forms of reasoning and argumentation in their everyday lives that can serve as intellectual resources in science learning. A major problem in science instruction is that teachers are not prepared to recognize the diverse ways in which these intellectual resources can be used in academic settings.

The Chèche Konnen Project promotes collaborative scientific inquiry among language minority and low-SES students, as they learn to use language, to think, and to act as members of a science learning community (Rosebery et al., 1992). The premise is that much can be learned about school science by examining science as it is practiced in professional communities. Although scientific practice in schools may not—and perhaps should not—mirror the scientific practice of actual research scientists, understanding the relationship between these two domains can help to clarify what it means to teach and learn science.

In the Chèche Konnen Project, the course of students' inquiry is not predetermined; rather, it grows directly out of students' own beliefs, observations, and questions. The investigation of one question leads to additional explorations initially unforeseen. Because science instruction is organized around students' own observations and interests, the "curriculum" emerges from the questions the students pose, the experiments they design, the arguments they engage in, and the theories they articulate. The teachers' role is to facilitate students' investigations of their own questions, while offering guidance and assistance as needed. The results indicated that students with limited English proficiency or limited science experience were capable of conducting scientific inquiry and appropriating scientific ways of knowing and reasoning after participating in science instruction designed to promote collaborative scientific inquiry (Rosebery et al., 1992).

Over the years, while expanding the view of science as reflexive and cognitively complex, research by the Chèche Konnen team has also considered the informal, everyday knowledge that students of diverse backgrounds bring to the learning process (Ballenger, 1997; Warren et al., 2001). Teachers identify students' linguistic and cultural experiences that can serve as intellectual resources for science learning. As students engage in scientific inquiry and argumentation, teachers identify intersections between students' everyday knowledge and scientific practices, and use these intersections as the basis for instructional practices. The results suggest that students from many different languages and cultures deployed sense-making practices—deep questions, vigorous argumentation, situated guesswork, embedded imagining, multiple perspectives, and innovative uses of everyday words to construct new meanings—that intersected in potentially productive ways with scientific practices.

Linguistic Processes in Science Instruction

Science instruction typically has failed to help ELLs learn science in ways that are meaningful and relevant to them, while also failing to help them develop proficiency in oral and written English. Two areas of research examining linguistic processes in science instruction are found in the literature: (a) inquiry-based science instruction to promote scientific discourse and/or English language proficiency; and (b) code-switching between students' home language and English, described below.

Several studies examined inquiry-based science instruction to promote scientific discourse and/or English language proficiency of students in the United States. Kelly and Breton (2001) examined how two bilingual elementary school teachers helped their students to engage in scientific inquiry through particular ways of framing problems, making observations, and engaging in spoken and written discourse practices. The results indicated that the processes of framing disciplinary knowledge and introducing students to conventionalized ways of observing, writing, speaking, and understanding required discursive work on the part of the teachers. This work included engaging students in conversations through questioning, reframing ideas, varying use of languages, making reference to other classroom experiences, and devising interactional contexts for students to "talk science" under varying conditions.

Merino and Hammond (2001) examined how nine elementary school teachers facilitated bilingual students' learning of science concepts and skills through writing. The teachers implemented a science-based interdisciplinary approach in which a series of science inquiry lessons were integrated with other subject areas of the school curriculum. ELLs showed improvements in writing skills that also demonstrated scientific understanding. The researchers suggested that in addition to producing narrative texts (a common practice in elementary schools), elementary students should be provided with experiences in other genres of writing in content areas such as science.

Rodriguez and Bethel (1983) examined the effectiveness of an inquiry approach to science and language teaching in order to develop classification and oral English communication skills among bilingual Mexican American third-grade students. The students in the experimental group participated in science inquiry lessons that required manipulation of objects, exploration, and interaction with peers and the teacher; those in the control group were taught with traditional science lessons developed by teachers in the school district. The results indicated statistically significant improvements for the experimental group in both classification and oral communication skills.

Amaral, Garrison, and Klentschy (2002) examined the impact of a 4-year intervention with elementary ELLs in a rural school district. In the district-wide local systemic reform initiative, students participated in kit- and inquiry-based science instruction that included the use of science notebooks. Although teachers and students had the freedom to use Spanish for facilitation of instruction, most instruction was in English in "bilingual" classes as well as in sheltered/transitional English (now called structured English immersion) classes. The science and writing assessment instruments were also in English. The results indicated that with both fourth- and sixth-grade students, science and literacy achievement increased significantly in proportion to the number of years that the students had participated in the program. In both grades, English proficient students performed significantly better than limited English proficient students in both science and writing.

A few studies looked specifically at linguistic code-switching in science classrooms. In the United States, Blake and Sickle (2001) worked with African American high school students on one of the Sea Islands in South Carolina. The students were characterized by dialect diversity, retention in special education, little or no coursework in mathematics and science, and failure to pass statewide assessments. Students were provided with a hands-on inquiry science curriculum, which was complemented by various techniques designed to promote their language development. Case studies of two students indicated that they became more sensitive to the language of the school and of the test. When they improved their ability to code-switch from the highly inferential local dialect to a more explicit and detailed Standard English, they improved their science achievement.

Similarly positive effects of code-switching in science education contexts were observed in African countries. In a study of rural elementary schools in Kenya, Cleghorn (1992) found that science content was made more accessible when teachers incorporated use of local languages in a variety of code-switching patterns rather than adhering strictly to the schools' policy of English-only instruction. Instruction that used code-switching was clearer than instruction that relied exclusively on either English or the local language. Use of local languages along with English provided a means for drawing on students' first language skills in the construction of meaning, linking the foreign cultural content of instruction to students' experiences outside of school, and connecting the concrete to the abstract. The researcher concluded that purposeful maintenance of students' first language assisted in the development of literacy skills in the target second language.

Setati, Adler, Reed, and Bapoo (2002) described how primary and secondary teachers and students in urban and rural schools in South Africa moved from informal, exploratory talk in students' respective home languages to discourse-specific talk and writing in English. The results indicated that few teachers and students were able to successfully "complete the complex journey" from informal, exploratory talk in the vernacular to discourse-specific talk and writing in English. South African language policy officially advocated additive bilingualism/multilingualism, but the standard practice of assessing students in English and the fact that rural students' only exposure to English was in school put pressure on teachers to use English as much as possible. Code-switching was thus perceived as a "dilemma," even though teachers felt the need to do it. The researchers argued that while students learn subject matter content through the medium of vernacular languages, they should also learn to talk in the formal, English-based discourses of science.

Discussion

Different researchers have proposed different approaches to science instruction based on their particular theoretical/conceptual perspectives. Research on culturally congruent instruction suggests that when students are not from the "culture of power" of the dominant society (e.g., Western science), teachers need to make that culture's rules and norms explicit and visible, so that students learn to cross cultural borders between their home and school. For students who have limited science experience or who come from backgrounds in which questioning and inquiry are not encouraged, teachers may move progressively along the teacher-explicit to student-exploratory continuum, to help students learn to take the initiative and assume responsibility for their own learning. In contrast, research on cognitively based science instruction suggests that teachers need to understand the complex dynamics between scientific practices and students' everyday knowledge. As teachers identify and incorporate students' linguistic and cultural experiences as intellectual resources for science learning, they provide opportunities for students to learn to use language, to think, and to act as members of a science learning community.

The studies on science instruction with ELLs in the United States emphasized hands-on, inquiry-based instruction, whereas studies conducted outside the United States focused on code-switching. Few studies undertaken in the United States posited any major instructional role for students' home languages, and the question of whether students were literate in the home language was not addressed. In contrast, studies conducted outside the United States were more likely to examine the role that students' home languages played in their science learning (e.g., code-switching). This points to the powerful influence of national and state language policies on research agendas and programs; in countries with a tradition of mother-tongue schooling (e.g., India), researchers are apparently less constrained in terms of exploring the intersections between school science and linguistic diversity.

Science Assessment

Research on science assessment with ELLs (both large-scale and classroom assessment) is extremely limited (Lee, 1999). Because assessment of ELLs tends to concentrate on basic skills in literacy and numeracy, other subjects such as science tend to be ignored. In addition, because science is often not part of large-scale or statewide assessments and because science usually does not count toward accountability measures even when it is tested, research on assessment accommodations in science for ELLs is sparse.

In terms of assessment accommodations, the 2000 NAEP report is the first since the inception of the series in 1969 to report results for students with disabilities and limited English proficiency (O'Sullivan et al., 2003). Two sets of results are reported: "accommodations-permitted" and "accommodations-not-permitted." Accommodations included, but were not limited to, one-on-one testing, small-group testing, access to bilingual dictionaries, extended time, reading aloud of directions, recording of students' answers by someone else, signing of directions (for deaf students), and use of magnifying equipment and large print books (for visually impaired students). At Grade 4, the accommodations-permitted results, which included slightly more students with disabilities and limited English proficiency because of the availability of accommodations, were 2 points lower than the accommodations-not-permitted results, and this difference was statistically significant. At Grades 8 and 12, there was no statistically significant difference between the two sets of results. Unfortunately, the results were not disaggregated by students with disabilities or limited English proficiency, because of the small number of each group of students at each grade level, with or without accommodations. The Grade 4 results were also confounded by the fact that the accommodations-permitted group included slightly more students with disabilities and limited English proficiency than the accommodation-not-permitted group.

Assessment for ELLs ideally should distinguish science knowledge from English language proficiency, although this is rarely done in research and assessment programs. Shaw (1997) examined the use of science performance assessment with ELL high school students. The school implemented bilingual education programs with extensive human and material resources for effective instruction of ELLs. The study focused specifically on a performance assessment task in sheltered science instruction taught by two teachers fluent in both English and Spanish. The results indicated that only the inquiry procedure, the most text-dependent item, was significantly affected by students' level of English proficiency. Conversely, graphs, calculations using an equation and a data table, and final summary questions were significantly affected by students' level of science knowledge. Thus there was no simple answer to the question of whether performance assessments accurately measured ELLs' science knowledge; instead, the answer depended on the assessment task in question.

There seem to be two opposing perspectives on valid and equitable assessment with ELLs. Whereas efforts have traditionally focused on eliminating the effects of students' home language and culture as a way to ensure test validity, an emerging approach advocates that understandings of home language and culture must be incorporated to guide the entire assessment process (Solano-Flores & Nelson-Barber, 2001; Solano-Flores & Trumbull, 2003). These researchers propose that ELLs be given the same items in both English and their first language—an approach that has the potential to produce more fine-grained understandings of the interactions among students' first and second language proficiency, students' content knowledge, and the linguistic and content demands of test items. Although this approach solves some problems, it presents its own challenges. For example, even when the same items are administered with ELLs in both English and the home language, ensuring the comparability of assessment instruments in the two languages is complicated. In the current policy context of high-stakes assessment and accountability, designing and implementing assessments for specific linguistic and cultural groups would be not only expensive but also open to psychometric and other technical problems (Abedi, 2004; Abedi, Hofstetter, & Lord, 2004). Possible solutions to this dilemma are further constrained by the spread of "English-only" legislation that prioritizes students' acquisition of English over their subject area knowledge.

Given the limited research, it is difficult to draw conclusions about how to ensure valid and equitable science assessment with ELLs. It is also unclear whether new assessment technologies and innovations present more hopes or obstacles to these students. In light of all of these challenges, assessment of ELLs remains one of the thorniest difficulties in educational policy and practice.

Science Teacher Education

In contrast to the growing diversity among students, the teaching profession is increasingly dominated by White female teachers (Jorgenson, 2000). Teachers of ELLs need to promote students' English language and literacy development as well as academic achievement in subject areas. This may require subject-specific instructional strategies that go beyond the general preparation in ESOL or bilingual education that many teachers receive.

Unfortunately, a majority of teachers working with ELLs believe that they are not adequately prepared to meet their students' learning needs, particularly in academically demanding subjects such as science (National Center for Education Statistics, 1999). Most teachers also assume that ELLs must acquire English before learning subject matter, although this approach almost inevitably leads such students to fall behind their English-speaking peers (August & Hakuta, 1997).

No study examining preparation of prospective science teachers with ELLs is found in the literature. A limited body of literature addresses professional development efforts to help practicing teachers enhance their beliefs and practices in integrating science with literacy for ELLs. These studies used qualitative research with a small number of participants (Fradd & Lee, 1995; Lee, 2004) or large-scale intervention research on school- or district-wide initiatives (Amaral et al., 2002; Hart & Lee, 2003; Lee, Hart, Cuevas, & Enders, 2004; Stoddart, Pinal, Latzke, & Canaday, 2002).

Stoddart et al. (2002) was based on the premise that inquiry-based science provides a particularly powerful instructional context for the integration of science content and second language development with ELLs. As part of a National Science Foundation–supported local systemic initiative, the study involved elementary school teachers of predominantly Latino ELLs. The preliminary analyses of teachers' work during the 5-week summer professional development program indicated change in teachers' understanding of science and language integration. This change typically involved a shift from a restricted view of the connections between inquiry science and language development to a more elaborated reasoning about the different ways that the two could be integrated.

In a series of studies over the years, Lee and colleagues have addressed elementary teachers' beliefs and practices in teaching science and literacy with linguistically and culturally diverse students. Fradd and Lee (1995) examined teachers' perceptions of science instruction at two elementary schools, one suburban and one urban, with high percentages of ELLs. Teachers in both schools expressed the belief that all students could learn science, stressed that science learning opportunities should be available to all students, and emphasized the need to promote language development during science instruction for all students. Despite these similarities, the two schools displayed clear contrasts. The urban schoolteachers perceived students' limited English proficiency and cultural difference as reasons for their difficulties in learning science. The teachers were not specific about instruction or articulate about their own beliefs regarding effective instructional approaches. In contrast, the suburban schoolteachers generally promoted science learning along with English language skills more effectively than those at the urban school.

Lee (2004) examined patterns of change in elementary teachers' beliefs and practices as they learned to teach English language and literacy as part of science instruction through their 3-year collaboration with the research team. Working with six bilingual Hispanic teachers of Hispanic students at two elementary schools, Lee described changes in teachers' beliefs and practices related to literacy instruction. Teachers gradually learned to provide effective linguistic scaffolding, helped students to acquire the conventions of standard oral and written English, and used multiple representational formats in oral and written communication. Overall, science instruction provided a meaningful context for English language and literacy development, while language processes provided the medium for understanding science.

As an expansion of Lee (2004), Lee and colleagues implemented similar, but less intensive, professional development opportunities to all third- and fourth-grade teachers (more than 50) from six elementary schools serving students with a range of ethnic, linguistic, and SES backgrounds and levels of English proficiency. Lee et al. (2004) examined the impact of the intervention on elementary teachers' knowledge, beliefs, and practices in inquiry-based science instruction. After participating in the intervention for a year, the teachers reported significantly enhanced knowledge of science content and stronger beliefs about the importance of science instruction with ELLs, although their actual practices did not show statistically significant change. In addition, Hart and Lee (2003) examined the intervention's impact on the teachers' beliefs and practices in integrating English language and literacy development as part of science instruction with ELLs. Teachers came to place greater emphasis on the importance of reading and writing in science instruction, express a broader and more integrated conceptualization of literacy in science, and provide more effective linguistic scaffolding to enhance scientific understanding.

As a result of the instructional intervention, third- and fourth-grade ESOL students in the study showed statistically significant gains in science and literacy (writing) achievement at the end of the school year (see the description of Lee et al., in press, under "Culturally Congruent Science Instruction" in the present article). They also demonstrated enhanced abilities to conduct science inquiry (see the description of Cuevas et al., 2005, under "Culturally Congruent Science Instruction" in the present article). Especially, at the end of the school year, bilingual Spanish/English-speaking students and those who exited from ESOL programs showed science and literacy achievement scores that were comparable to or higher than those of monolingual English-speaking students, thus narrowing achievement gaps.

Amaral et al. (2002) examined professional development in promoting science and literacy with predominantly Spanish-speaking elementary students as part of a district-wide local systemic reform initiative. Over a period of 4 years, all elementary teachers in the school district received at least 100 hours of professional development, in-classroom professional support from a cadre of resource teachers, and complete materials and supplies for all the science units at each grade level. The results indicated that science and literacy achievement of ELLs increased in direct relation to the number of years they participated in the program (see "Linguistic Processes in Science Instruction" in the present article). English proficient students performed significantly better than limited English proficient students in both science and writing.

The results of the studies, described above, indicated positive outcomes in teachers' beliefs and practices after their participation in professional development activities. Some teachers who were already committed to embracing student diversity in science education became more committed through professional development opportunities. Others, who did not consider student diversity to be an important factor in science education, came to recognize and accept its importance. Of particular note was the positive impact on ELLs' science or literacy achievement, or both, evidenced in professional development interventions (Amaral et al., 2004; Cuevas et al., 2005; Lee et al., in press).

Conclusions, Research Agenda, and Implications for Practice

The present research synthesis offers conclusions in two areas: (a) key features of the literature with regard to theoretical perspectives and methodological orientations; and (b) key findings in the literature. Future research should address current limitations in theory-building and in research methods, while pursuing those areas that demonstrate promising findings with regard to improving science outcomes and narrowing gaps. The existing literature, although limited, offers important implications for educational practice.

Conclusions

Key Features of the Literature

Research on ELLs in science education is a new and developing field; most articles have been published since the mid-1990s. Studies have been conducted from a range of theoretical and disciplinary perspectives. Although the studies have used a variety of research methods, many were conducted using qualitative methods, whereas experimental or quasi-experimental studies were rare (e.g., Dixon, 1995; Rodriguez & Bethel, 1983). No meta-analysis of statistical research studies was found in the literature.

Given the emerging nature of the research, there are many conceptual reviews or articles explicating particular issues or framing such issues for research pursuits. There are only a small number of programmatic lines of research carried out by research teams, notably the Chèche Konnen project and the Science for All project by Lee (for a summary of both projects, see Lee, 2002). The majority of studies are small-scale, descriptive research conducted as single studies by individual researchers. Relatively few intervention-based studies are on a large scale (e.g., Amaral et al., 2002; Hart & Lee, 2003; Lee et al., 2004; Stoddart et al., 2002).

The relationship between educational processes and students' science outcomes (particularly achievement data) is tenuous in most studies. Only two studies (Amaral et al., 2002; Lee et al., in press) examined the impact of intervention programs on ELLs' achievement in both science and literacy, achievement results at different levels of English proficiency, and achievement gaps among linguistic groups.

The degree of theoretical and methodological sophistication with which linguistic issues are treated in the science education literature is uneven. Most studies failed to consider complexities inherent in the construct of language or intersections of this construct as it relates to science education. The disciplinary "tunnel vision" of much science education research has frequently given rise to research designs that are fundamentally flawed and interpretations that are markedly ethnocentric or uninformed with regard to linguistic or cultural processes. However, a few studies (conducted outside the United States) displayed greater methodological rigor and theoretical depth in this regard. They demonstrated a commendable attention to the sociolinguistic context of science education, including features of language policy and "language ecology" that exert a powerful influence on instructional processes (Cleghorn, 1992; Kearsey & Turner, 1999).

Key Findings in the Literature

Students from diverse linguistic backgrounds come to school with already constructed knowledge, including their home language and cultural values, acquired in their home and community environments. Such knowledge serves as the framework for constructing new understandings. However, some aspects of students' experience may be discontinuous with science disciplines as traditionally defined in Western science. Furthermore, even those experiences of ELLs that could potentially serve as intellectual resources are generally marginalized from school science.

The education system often fails to provide adequate instructional scaffolding for ELLs in science classrooms. For example, science curriculum seldom considers development of ELLs' oral and written proficiency in English. The mediation of science instruction by the linguistic and cultural knowledge of the mainstream serves to reduce science learning opportunities for ELLs. Assessment practices are differentially biased, since ELLs are often not assessed in their home language. These assessment practices may result in a major underestimation of ELLs' science knowledge, in that such practices conflate science knowledge with other types of linguistic and cultural knowledge.

When ELLs are provided with equitable learning opportunities, they demonstrate academic achievement. Learning environments that articulate the relation of science disciplines with ELLs' linguistic and cultural practices enable them to capitalize on their experiences as intellectual resources for science learning and to explore and construct meanings in ways that relate science to their linguistic and cultural identities. Ideally, students could become bilingual and bicultural border-crossers between their own cultural and speech communities and the science learning community, able to perform competently in a variety of contexts.

Although effective learning environments share the principle of articulating students' linguistic and cultural experiences with science disciplines, specific approaches to achieving this goal differ from one theoretical perspective to another. For example, from a cross-cultural perspective, students' cultural beliefs are sometimes inconsistent with Western science, and teachers need to help students make smooth transitions between their home cultures and the culture of science (Costa, 1995; Jegede & Aikenhead, 1999; Snively & Corsiglia, 2001). In contrast, from a cognitive science perspective, there is significant overlap between students' explorations of the natural world and the way that science is practiced by scientists (Rosebery et al., 1992; Warren et al., 2001). Teachers need to understand the complex dynamics between scientific practices and students' everyday knowledge and must facilitate and guide students' investigations of their own questions as they learn to speak, read, write, think, and act as members of a science learning community.

Science education for ELLs needs to be understood within the current policy context of high-stakes assessment and accountability, where science is generally not salient. Testing in science is not required by federal policies until 2007, according to the No Child Left Behind Act of 2002, and has not been part of accountability measures in many states (Council of State Science Supervisors, n.d.). Science instruction is often largely ignored, especially with ELLs because of the perceived urgency of developing English language proficiency. School funding and resources for science instruction are often overlooked because of the pressure to support core subjects, including reading, writing, and mathematics. These tensions become more acute in urban school districts or inner-city schools where student diversity is greater and educational opportunities are more limited.

Research Agenda for the Future

Considering that research on diversity and equity in science education is a new and emerging literature, future research can pursue a multitude of issues in a multitude of ways. However, priorities for future research need to be identified in order to produce research outcomes that are rigorous, cumulative, and usable for educational practice. Some of the directions proposed below grew out of the segments of the literature that have shown promise for establishing a robust knowledge base, whereas others are proposed because there is limited research in these areas despite the urgent need for a knowledge base.

Science Outcomes

One area that is ripe for investigation involves conceptions and measurement of science outcomes. Although science educators (researchers, teachers, policymakers, and others) share the dual goals of improving science outcomes and eliminating gaps, existing research programs often do not address student outcomes, especially quantitative achievement data. Such data should not be the only measure of student outcomes in educational research, but they provide important information when accompanied by narrative descriptions about other types of student outcomes, which are common in research studies. The existing literature also does not address ELLs' agency and empowerment, although these outcomes have been advocated from a critical theory perspective in the larger literature on nonmainstream students in science education (Lee & Luykx, in press).

Several issues concerning science achievement deserve special attention. First, future research should explicitly attempt to establish the link between students' learning processes and outcomes. Second, more research is needed to examine the effectiveness of educational interventions on achievement gaps. Third, longitudinal analysis of student achievement across several grade levels is needed, as it is now conspicuously absent from the current literature. Fourth, literacy outcomes should be considered along with science outcomes with ELLs. Finally, agency and empowerment of ELLs should be considered as a measure of science outcomes.

Student Diversity

Studies focusing on ELLs' science learning seldom consider the organic link between home language and cultural identity. Future research needs to conceptualize the interrelated effects of language and culture on students' science learning in more nuanced ways. Furthermore, there is a need for studies that combine multiple theoretical perspectives on science learning, rather than focusing on one to the exclusion of others. This will require multidisciplinary efforts bringing together research traditions that have too often been developed in isolation from (or even in opposition to) one another.

Future research on ELLs needs to consider science learning/achievement, literacy development, and English proficiency as conceptually distinct but interrelated variables, and to operationalize the complex interplay of multiple variables in methodologically rigorous research designs. Science educators and researchers also need to engage more deeply the broad scholarship on classroom discourse, second language acquisition, and literacy development. Although this literature has seldom addressed school science directly, its potential contribution to science education is considerable.

Diversity of Student Experiences in Relation to Science Curriculum and Instruction

A major area of future research should be the linguistic and cultural experiences that ELLs bring to the science classroom and the articulation of these experiences with science disciplines (Lee & Fradd, 1998; Warren et al., 2001). Researchers should aim to identify linguistic and cultural experiences that can serve as intellectual resources for science learning, as well as beliefs and practices that may be discontinuous with the specific demands of science disciplines. To do so requires a balanced view of ELLs' intellectual resources and the challenges they face in learning science.

Another area for future research is the demands involved in learning science through inquiry. Although current reforms in science education emphasize inquiry as the core of science teaching and learning (National Research Council, 1996, 2000), inquiry presents challenges to all students, as it requires a critical stance, scientific skepticism, and a tolerance for uncertainty and ambiguity. These challenges are greater for students whose homes and communities do not encourage inquiry practices (for detailed discussion, see Fradd & Lee, 1999; Lee, 2003, 2004), those who have limited experience with school science (Duran et al., 1998; Moje et al., 2001), and those who have been historically disfranchised by the social institutions of science and do not see the relevance of science to their daily lives or to their future (Eisenhart et al., 1996; Rodriguez, 1997). Future research may identify essential aspects of inquiry-based teaching and learning and investigate how these play out with the experiences of ELLs.

Still another area of research that has been dominating the landscape of science education in general but has largely been ignored with ELLs involves the use of computer technology in science curriculum and instruction. A very small number of studies on the use of computer-based programs showed positive science outcomes with ELLs (Buxton, 1999; Dixon, 1995). Further research may examine the impact of computer technology on science and literacy outcomes with diverse groups of ELLs.

High-Stakes Assessment in Science

The currently predominant educational policy, which is particularly consequential for ELLs, involves high-stakes assessment and accountability (Abedi, 2004; Abedi et al., 2004). After almost a decade of high-stakes assessment in reading, writing, and mathematics, more states are now moving to incorporate science as well. This trend coincides with the planned federal policy on science assessment within the No Child Left Behind Act, according to which science will be included in accountability measures starting in 2007.

This policy change at the federal and state levels may bring about dramatic changes in many aspects of science education. Complex issues related to assessment abound, such as which students are to be included in accountability systems, what assessment accommodations are appropriate, and how content knowledge may be assessed separately from English proficiency or general literacy (O'Sullivan et al., 2003). A basic concern is that ELLs' science achievement is underestimated when they are not allowed to demonstrate their knowledge and abilities in their home language (Solano-Flores & Trumbull, 2003). On the other hand, if science instruction is predominantly in English, simply assessing ELLs in the home language will not guarantee an accurate picture of their science knowledge and abilities. Future research may examine how policy changes in high-stakes assessment and accountability influence various aspects of science education with ELLs.

Science Teacher Education

The literature is replete with accounts of the difficulties that science teachers (who are mostly from mainstream backgrounds) experience in teaching ELLs. These difficulties are likely to be exacerbated as diversity within the teaching population fails to keep pace with increasing diversity among students (Jorgenson, 2000).

Future research may address how to design teacher education programs to enable preservice and practicing teachers to articulate science disciplines with students' linguistic and cultural practices, particularly when the discontinuities between the two domains are large. Research may also examine how teachers' knowledge, beliefs, and practices evolve as they reflect on ways to integrate these two domains. In addition, research may examine the challenges involved in bringing about change with teachers who deride student diversity, resist multilingual and multicultural views, or reproduce racism through their teaching practice.

Implications for Educational Practice

To achieve the ideal of educational equity in the midst of increasing linguistic and cultural diversity of the school-age population, school science must value and respect the experiences that ELLs bring from their home and community environments, articulate their linguistic and cultural knowledge with science disciplines, and offer educational resources and funding to support their learning. Policies and practices at every level of the education system should be in concert to provide equitable learning opportunities for all students. The results of this review indicate that, provided with such opportunities, ELLs are capable of demonstrating science and literacy achievement. Thus we must conclude that many, if not most, of the difficulties faced by ELLs reside not in themselves, their families, or their communities, but in the education systems serving them.

Students of all backgrounds should be provided with academically challenging learning opportunities that allow them to explore scientific phenomena and construct scientific meanings based on their own linguistic and cultural experiences. At the same time, some students may need more explicit guidance in articulating their linguistic and cultural experiences with scientific knowledge and practices. The proper balance of teacher-directed and student-initiated activities may depend on the degrees and types of continuity or discontinuity between science disciplines and students' backgrounds, the extent of students' experience with science disciplines, and the level of cognitive difficulty of science tasks. Teachers (and curriculum designers) need to be aware of students' differing needs when deciding how much explicit instruction to provide and to what degree students can assume responsibility for their own learning (Fradd & Lee, 1999; Lee, 2002).

Hands-on, inquiry-based instruction provides opportunities for ELLs to develop scientific understanding, engage in inquiry, and construct shared meanings more actively than with traditional textbook-based instruction, for various reasons (Lee & Fradd, 1998; Rosebery et al., 1992). First, hands-on activities are less dependent on formal mastery of the language of instruction, thus reducing the linguistic burden on ELLs. Second, collaborative, small-group work provides structured opportunities for developing English proficiency in the context of authentic communication about science. Third, inquiry-based science instruction promotes students' communication of their understanding in a variety of formats, including written, oral, gestural, and graphic. Finally, by engaging in science inquiry, ELLs develop their English grammar and vocabulary as well as their familiarity with scientific genres of writing.

Professional development to promote science as well as English language and literacy development with ELLs involves teacher knowledge and practices in multiple areas. First, in addition to ensuring that ELLs acquire the language skills necessary for social communication, teachers need to promote ELLs' development of general and content-specific academic language functions, such as describing, explaining, comparing, and concluding (Wong-Fillmore & Snow, 2002). Second, teachers must be able to view language within a human development perspective if they are to formulate developmentally appropriate expectations about language comprehension and production over the course of students' learning of English. Finally, teachers need to be able to apply this knowledge to the teaching of general and content-specific academic language. The amalgamation of these three knowledge sources should result in teaching practices that engage students of all levels of English proficiency in academic language learning, engage students in learning activities that have multiple points of entry for students of differing levels of English proficiency, provide multiple modes for students to display learning, and ensure that students participate in a manner that allows for maximum language development at their own level.

School-wide professional development can provide valuable insights for large-scale implementation. Several studies involved all teachers at certain grades or from entire schools rather than volunteer teachers (Amaral et al., 2002; Hart & Lee, 2003; Lee et al., 2004). School-wide initiatives reveal both advantages and limitations. On the one hand, collective participation of all teachers from the same school or grade level in professional development activities allows teachers to develop common goals, share instructional materials or assessment tools, and exchange ideas and experiences arising from a common context. On the other hand, unlike programs staffed by volunteer teachers seeking opportunities for professional growth, school-wide implementation inevitably includes teachers who are not interested in or who even resist participation. In addition, the intensity of professional development activities may be compromised by limits on the number of days that teachers may be out of their classrooms, the pressure to prepare for high-stakes assessment, or other such constraints. Given that such initiatives include all teachers in the participating schools or districts, rather than a self-selected group of volunteer teachers with an interest in "teaching science for diversity," their beliefs and practices may be more representative of teachers in general. These results have implications for further large-scale implementation (i.e., scale up) of the initiatives in varied educational settings.

In closing, the literature on the intersection between school science and students' linguistic and cultural diversity is currently insufficient to the task of effectively addressing persistent gaps in science outcomes, but it points in some promising directions. Deeper examination of the complex relationships among factors influencing science outcomes, combined with greater attention to the potential contributions of multiple theoretical perspectives and research methods, should produce powerful additions to the existing knowledge base in this emerging field. Just as ELLs must become bilingual and bicultural border-crossers to gain access to learning science, so teachers must learn to cross cultural and linguistic boundaries to make school science meaningful and relevant for all students. Similarly, researchers must also breach the barriers separating different theoretical and methodological traditions, if they are to disentangle the complex connections between student diversity and science education.

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APPENDIX

Features of the Studies Cited

Topic	Study	Participants and research setting	Focus of intervention	Language treatment	Data collection	Data analysis
Science learning						
Cultural beliefs and practices	Lee, Fradd, & Sutman (1995); Lee & Fradd (1996a, 1996b)	32 fourth-grade students and eight teachers matched by language, culture, and gender outside the classroom setting	—	Bilingual (English and Spanish, or English and Haitian Creole)	Interviews, writing, and drawing samples	Descriptive statistics (mean and *SD*), discourse analysis
Scientific reasoning and argumentation	Rosebery, Warren, & Conant (1992)	Middle school (combined seventh and eighth grades) and high school students and their teachers in two bilingual classrooms	Scientific inquiry and argumentation	Bilingual (English and Haitian Creole)	Classroom observations, interviews, writing samples	Discourse analysis, qualitative analysis, statistical analysis (*t* tests)
	Ballenger (1997)	Fifth- through eighth-grade students and a team of three teachers in a multi-grade bilingual classroom	Scientific inquiry and argumentation	Bilingual (English and Haitian Creole)	Classroom observations	Discourse analysis
	Warren et al. (2001)	One fifth-grade student and one sixth-grade student, and their teachers, in two bilingual classrooms	Scientific inquiry and argumentation	Bilingual (English, Haitian Creole, and Spanish)	Classroom observations, interviews	Case studies, discourse analysis
Linguistic processes	Duran, Dugan, & Weffer (1998)	14 tenth-grade Mexican American students and two teachers,	Scientific understanding and discourse	English	Classroom observations, interviews,	Interpretative/ ethnographic

	one in biology and the other in reading, in a Saturday enrichment program at a university			written products	
Torres & Zeidler (2002)	380 tenth-grade English- and Spanish-speaking students at a high school	—	English	Testing	Statistical analysis (ANOVA)
Tobin & McRobbie (1996)	11th- and 12th-grade Chinese Australian students in a high school chemistry class in Australia	—	English	Classroom observations, interviews, questionnaire	Interpretative
Curtis & Millar (1988)	About 500 high school students (Asian and British) at two high schools in the United Kingdom	—	English	Testing through free writing	Statistical analysis (*t* tests)
Kearsey & Turner (1999)	217 high school students (various bilingual groups and British) at six high schools in the United Kingdom	—	Bilingual (English and various home languages)	Questionnaire, cloze tasks, interviews	Descriptive (frequencies), statistical analysis (*t* and *F* tests)
Lynch, Chipman, & Pachaury (1985a, 1985b)	High school students (1,635 Tasmanian and 826 Indian) at six Tasmanian high schools and eight Indian high schools	—	English-speaking Tasmanian and Hindi-speaking Indian students	Testing	Statistical analysis (*t* and chi-square tests)

(continued)

APPENDIX (*Continued*)

Topic	Study	Participants and research setting	Focus of intervention	Language treatment	Data collection	Data analysis
	Lynch (1996a, 1996b)	32 Tasmanians (third and sixth graders) and 40 Filipinos (Tagalog- and B'laan-speaking sixth graders) at Tasmanian and Philippine primary schools	—	English-speaking Tasmanians, and Tagalog- and B'laan-speaking Filipinos	Interviews	Discourse analysis
Science curriculum						
	Barba (1993)	Predominantly Hispanic/Latino elementary students and their teachers, mostly English-speaking, in 57 elementary science classes in bilingual/bicultural settings	—	Primarily English	Classroom observations, interviews, instructional materials	Descriptive statistics (frequencies)
	Hampton & Rodriguez (2001)	Predominantly Spanish-speaking elementary students, K–5, and more than 100 university interns in 62 classrooms at three elementary schools	Hands-on, inquiry science	Bilingual (English and Spanish)	Testing with students, interviews and questionnaires with university interns and teachers	Descriptive statistics (frequencies), qualitative analysis

	Fradd, Lee, Sutman, & Saxton (2002)	More than 500 fourth-grade students (Spanish-, Haitian Creole-, and English-speaking) and their teachers in all fourth-grade classrooms at six elementary schools	Integration of science, English language and literacy, and students' home language and culture	English	Testing	Statistical analysis (t tests)
	Buxton	Combined second and third grades, Spanish-speaking students in a two-way bilingual classroom	Scientific discourse through computer modeling	Bilingual (English and Spanish)	Classroom observations, classroom artifacts, interviews	Qualitative analysis
	Dixon (1995)	Eighth-grade English proficient (EP) and limited English proficient (LEP) students from four classes in the treatment group and five classes in the control group	Visualization and concept development through computer software	English	Testing	Statistical analysis (ANCOVA)
Science instruction						
Culturally congruent instruction	Westby, Dezale, Fradd, & Lee (1999)	Three Spanish-speaking teachers, one Haitian Creole-speaking teacher, and their students in four fourth-grade classrooms at two elementary schools	Scientific understanding, inquiry, and discourse	English	Videotaped lessons	Discourse analysis, descriptive statistics (frequencies)

(continued)

APPENDIX (*Continued*)

Topic	Study	Participants and research setting	Focus of intervention	Language treatment	Data collection	Data analysis
	Moje, Collazo, Carillo, & Marx (2001)	One Spanish-speaking science teacher and predominantly Spanish-speaking seventh-grade students in a seventh-grade classroom	Scientific discourse, inquiry, and understanding	English	Classroom observations, interviews, artifacts	Qualitative analysis, discourse analysis
	Lee (2004)	Six Spanish-speaking elementary teachers and their fourth-grade students in six fourth-grade classrooms at two elementary schools	Integration of science, English language and literacy, and students' home language and culture	English	Classroom observations, interviews, questionnaire	Qualitative analysis
	Lee, Deaktor, Hart, Cuevas, & Enders (in press)	53 third- and fourth-grade teachers and 1,523 students (Spanish-, Haitian Creole-, and English-speaking) in all third- and fourth-grade classrooms at six elementary schools	Integration of science, English language and literacy, and students' home language and culture	English	Testing in science and literacy (writing)	Statistical analysis (*t* tests)
	Cuevas, Lee, Hart, & Deaktor (in press)	25 third- and fourth-grade students (Spanish-, Haitian Creole-, and English-speaking) in	Scientific inquiry	English	Interviews	Statistical analysis (*t* tests), discourse analysis

		seven third- and fourth-grade classrooms at six elementary schools				
Cognitively based instruction	Rosebery et al. (1992); Ballenger (1997); Warren et al. (2001)	See above				
Linguistic processes	Barba (1993)	See above				
	Kelly & Breton (2001)	Two Spanish-speaking elementary teachers and predominantly Spanish-speaking students in two fifth-grade classrooms and one third-grade bilingual classroom at two elementary schools	Scientific discourse	Bilingual (English and Spanish)	Classroom observations	Discourse analysis
	Merino & Hammond (2001)	Nine third-through-fifth-grade teachers and their bilingual students at two elementary schools using interdisciplinary curriculum for ELLs	Scientific writing	English	Classroom observation, interviews, writing samples	Qualitative analysis
	Rodriguez & Bethel (1983)	64 bilingual Mexican American third-grade students and their teachers at an elementary school	Scientific inquiry	Unclear	Testing	Statistical analysis (ANOVA)

(continued)

APPENDIX (*Continued*)

Topic	Study	Participants and research setting	Focus of intervention	Language treatment	Data collection	Data analysis
	Amaral, Garrison, & Klentschy (2002)	615 fourth-grade students and 635 sixth-grade students at all elementary schools in a school district	Kit- and inquiry-based science, and English literacy (writing)	English	Testing in science and literacy (writing)	Statistical analysis (ANOVA)
	Blake & Sickle (2001)	Nine African American high school students speaking their island dialect at a high school	Hands-on inquiry science and English literacy (writing)	Code-switching between island dialect and English	Case studies	Case studies
	Cleghorn (1992)	Elementary teachers and their students in Kenya in all classrooms at three rural elementary schools in Kenya	—	Code-switching between home languages and English	Classroom observations	Ethnographic
	Setati, Adler, Reed, & Bapoo (2002)	25, 23, and 18 teachers in each of 3 years (including math, science, and English teachers) and their students at 10 rural and urban primary and secondary schools in South Africa	—	Code-switching between home languages and English	Classroom observations, interviews, questionnaires, student work samples	Case studies

Science assessment						
	Shaw (1997)	96 high school students of diverse languages and two teachers fluent in English and Spanish during five consecutive periods of sheltered science classrooms at a high school	A 4-day performance assessment task involving open-ended inquiry and hands-on investigation	English	Classroom observations, interviews, questionnaires, testing	Qualitative case study, statistical analysis (ANOVA)
	Solano-Flores & Nelson-Barber (2001)	*Note:* This is not an empirical study; instead, the article proposes the concept of cultural validity using examples from Spanish-speaking and Alaskan Yup'ik students in science assessment settings.				
Science teacher education	Fradd & Lee (1995)	Spanish- and Haitian Creole-speaking fourth-grade elementary students, teachers, and administrators at two elementary schools, one suburban (mostly Spanish-speaking) and one urban (mostly Haitian Creole-speaking)	—	Bilingual	School visits, interviews	Case studies

(continued)

APPENDIX (*Continued*)

Topic	Study	Participants and research setting	Focus of intervention	Language treatment	Data collection	Data analysis
	Lee (2004)	See above				
	Lee, Hart, Cuevas, & Enders (2004); Hart & Lee (2003)	53 third- and fourth-grade teachers working with Spanish-, Haitian Creole-, and English-speaking students in all third- and fourth-grade classrooms at six elementary schools	Integration of science, English language and literacy, and students' home language and culture	English	Classroom observations, questionnaires, interviews	Statistical analysis (t tests), qualitative analysis
	Stoddart, Pinal, Latzke, & Canaday (2002)	24 elementary school teachers of predominantly Hispanic/Latino students in a summer professional development program	Science and English language integration	English	Interviews	Qualitative analysis
…	Amaral et al. (2002)	See above				

Note. Within each category, studies are presented in the order that they are described in the article.