# Equity for Linguistically and Culturally Diverse Students in Science Education: A Research Agenda

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*As the student population in the nation's schools becomes more linguistically and culturally diverse, it is essential to establish a knowledge base that promotes academic achievement and equity for all students. Based on the conception of equity from a cultural anthropology or cross-cultural perspective, the article addresses issues of equity in science learning and teaching for students from diverse languages and cultures. It provides a synthesis of major issues and research findings for effective classroom practices in the multicultural science education literature. Recommendations are also offered for a research agenda that contributes to achieving the goal of science for all, including students from diverse languages and cultures.*

As the student population in the nation's schools becomes more linguistically and culturally diverse (García, 1999; National Center for Education Statistics, 1999), it is essential to establish a knowledge base to promote academic achievement and equity for all students. Such a knowledge base requires consideration of students' linguistic and cultural experiences in combination with expectations for high academic standards (Darling-Hammond, 1996; McLaughlin, Shepard, & O'Day, 1995).

This article is an attempt to contribute to an emerging literature on academic learning with students from diverse languages and cultures (August & Hakuta, 1997; García, 1999). It focuses on students in the process of acquiring the language, culture, and discourse of the U.S. mainstream—non-White students whose home languages are other than English and who often reside in low-income families (García, 1999; National Center for Children in Poverty, 1995). Issues discussed are applicable, to varying degrees, to other student groups who have also been marginalized in science education, including rural and working class Whites. Indeed, the interplay of language, culture, and social class is complex. For example, individuals from certain cultural backgrounds share cultural values regardless of socioeconomic status (SES), yet SES differences manifest

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within the same culture (e.g., Lee, 1999b). Unfortunately, much of the education literature on language and culture does not address differences in terms of SES or individual factors. For example, Rodríguez (1998a) points out that in large-scale science assessments, there is little information about disaggregation of results for SES-by-ethnic groups or subgroups within an ethnic group (e.g., Mexican Americans, Chicanos/as, Puerto Ricans, and students from various Latin American countries within the generic category of Hispanics).

Students from diverse languages and cultures come to school with previously constructed knowledge, including their home language and cultural values, from home and community environments. When these students are provided with equitable learning opportunities, they can capitalize on their linguistic and cultural experiences as intellectual resources for new learning in science classrooms. However, these experiences are sometimes discontinuous with science disciplines as traditionally defined in Western modern science. The challenge facing these students involves the disconnection between their own cultural knowledge and science disciplines and between the primary discourse in the home and community and secondary discourse in school (Atwater, 1994; Cobern & Aikenhead, 1998; Lee, 1999a; Moje, Collazo, Carillo & Marx, 2001).

In science education, ‘‘scientific inquiry is at the heart of science and science learning’’ (National Research Council, 1996, p. 15) and ‘‘inquiry into authentic questions generated from student experiences is the central strategy for teaching science’’ (p. 31). Although scientific inquiry is a challenge for most students (Minstrell & van Zee, 2000), it presents additional challenges for students from cultures that do not encourage them to engage in inquiry practices of asking questions, designing and implementing investigations, and finding answers on their own (Arellano et al., 2001; Jegede & Okebukola, 1992; McKinley, Waiti, & Bell, 1992; Solano-Flores & Nelson-Barber, 2001). Cultural norms may also prioritize respect for teachers and other adults as authoritative sources of knowledge, rather than the development of theories and arguments based on evidence and reasoning. Such discontinuities between cultural expectations and scientific practices require students to shift between different types of knowledge, practices, and discourse if they are to have access to school science without abandoning their home culture. Teachers, in turn, must integrate their knowledge of students' language and culture with knowledge of science disciplines if they are to make science accessible and meaningful for all students.

This article considers equity in science learning and teaching from a cultural anthropology or cross-cultural perspective. According to this perspective, science learning and achievement occur when students successfully participate in mainstream science, while also valuing alternative ways of knowing in their everyday worlds (Aikenhead, 1996; Cobern & Aikenhead, 1998; Maddock, 1981; Phelan, Davidson, & Cao, 1991; Pomeroy, 1994). This orientation considers the contributions and strengths of both mainstream science and alternative ways of knowing (Lee & Fradd, 1998; Loving, 1997; Stanley & Brickhouse, 1994, 2001). Students should have access and opportunities to learn the high-status knowledge of mainstream science as it is practiced in the science community, taught in school science, and presented in national standards documents (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996). At the same time, alternative ways of knowing should be recognized and valued. This balanced orientation emphasizes academic achievement as well as cultural identity. It leads students to acquire the language of science as well as their home languages, to understand the culture of science as well as their own cultures, and to behave competently across social contexts.

This article addresses pedagogical issues around equity in science learning and teaching for students from diverse languages and cultures. From an anthropological perspective based on the multicultural science education literature, the article provides a synthesis of major issues and research findings for effective classroom practices (i.e., what we know) and offers recommendations for a research agenda (i.e., what we need to know). First, the article reviews the literature indicating alternative ways of knowing in science with diverse students. The discussion points out that students' language and culture may be sometimes discontinuous with science disciplines, posing potential difficulties for these students in learning science. Second, the article presents an emerging literature on effective instructional scaffolding with diverse students. The discussion highlights how teachers can articulate the relationship between science disciplines and students' language and culture when the two domains are discontinuous as well as continuous. While addressing various aspects of science learning and teaching, it highlights scientific inquiry as central to science education. Finally, the article offers a research agenda that can contribute to achieving the goal of science for all.

## EQUITY IN SCIENCE LEARNING

All students have developed ways of understanding the natural world based on personal experiences and environments (Driver, Asoko, Leach, Mortimer, & Scott, 1994; O'Loughlin, 1992). For students from diverse backgrounds, learning is enhanced—indeed, made possible—when it occurs in contexts that are linguistically and culturally meaningful and relevant to them. Thus, it is important to use the linguistic and cultural resources that the students bring to the science classroom, even though such resources may not be easily recognized by the mainstream

(Lee & Fradd, 1998; Moje et al., 2001; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). At the same time it is important to examine the extent to which students' linguistic and cultural knowledge and experiences are continuous or discontinuous with Western modern science. Knowing specific areas of continuity or discontinuity between science disciplines and students' language and culture help them learn high-status knowledge while valuing cultural knowledge and practices. Rodríguez (1998b) states, "all learners at any grade level must be provided with equitable opportunities for success [in science]" (p. 591). Atwater (1996) also emphasizes the importance of "providing equitable opportunities for *all* students to learn *quality* science" (p. 822, original emphasis).

A caution should be kept in mind in interpreting general patterns with diverse student groups. Overemphasizing differences between groups tends to mask variations within a group or among individuals. Group differences should not be reduced to a measure of central tendency or construed as implying homogeneity among group members. Indeed, intragroup or individual variation is a complicated issue with students from diverse languages and cultures, considering the vast range of proficiency levels in the home language and English, social class, immigration history, acculturation to mainstream society, and family orientations toward education. This tension regarding differences among groups, subgroups, and individuals presents a challenge for both researchers and educators. Although knowledge about group patterns offers important insights about what is typical, there is a danger of reinforcing stereotypes based on group membership (Eisenhart, 2001). Knowledge of group patterns serves as a guideline, not as a prescription, and it needs to be adjusted by considering sub-group or individual differences within or outside the boundaries of general patterns.

## ALTERNATIVE WAYS OF KNOWING

The culture of Western science is foreign to many students, both Western and non-Western. All students develop their commonsense understanding about the natural world through personal experiences. Scientific conceptions, however, are often counterintuitive and may not coincide with students' sense making in their everyday life. The large body of literature on misconceptions, preconceptions, alternative conceptions, naive conceptions, or conceptual change indicates students' difficulties in learning scientific conceptions (see the summary of the literature in American Association for the Advancement of Science, 1993).

The challenge in science learning may be greater for students who bring to the science classroom views of science and ways of knowing from their cultures that are sometimes discontinuous with the nature of science or the way science is taught in school (Atwater, 1994; Baker, 1998; Barba, 1993; Barba & Reynolds, 1998; Brickhouse, 1998; Gallard, 1993; Garaway, 1994; George, 1992; Howes, 1998; Matthews & Smith, 1994; Nelson-Barber & Estrin, 1995; Rakow & Bermúdez, 1993; Rennie, 1998). The literature indicates discontinuities between science disciplines, as defined by the Western modern science tradition, and cultural knowledge and practices of diverse students. The following examples illustrate such discontinuities in terms of scientific understanding, inquiry, discourse, and habits of mind—all practices that are essential to scientific inquiry.

Understanding involves integration of new knowledge with prior knowledge and experience (Driver et al., 1994). With students from diverse languages and cultures, the use of culturally familiar examples, analogies, and contexts relates science to their backgrounds (Barba, 1993; Cobern & Aikenhead, 1998; Lee & Fradd, 1998). Unfortunately, consideration of students' prior knowledge and experience from diverse languages and cultures rarely happens for various reasons (Atwater, 1994; Eisenhart, Finkel, & Marion, 1996; Rodríguez, 1997). Traditional textbooks or standardized curricula often do not use examples from diverse backgrounds (Ninnes, 2000). Some teachers may find it difficult to communicate with diverse students who come from distinctly different linguistic and cultural backgrounds. Others may assume that the students have no prior knowledge. Still others may perceive the students' languages and cultures as irrelevant to science teaching and learning, especially if they consider science to be culture-free (Banks, 1993a; Lee, 1999a; Peterson & Barnes, 1996; Stanley & Brickhouse, 1994, 2001).

The emphasis on "scientific inquiry into authentic questions generated from student experiences" (National Research Council, 1996, p. 31) poses challenges to all students. Students experience difficulties performing the various phases of inquiry as they ask appropriate questions, find and synthesize information, design investigations, monitor scientific procedures, and draw valid conclusions (Krajcik, Mamlok, & Hug, 2001). The challenge may be greater if students' cultural values and practices expect them to unquestioningly accept teachers' authority, rather than promoting the students' questioning, exploration, or alternative solutions (Arellano et al., 2001; Fradd & Lee, 1999; Hodson, 1993; Jegede & Okebukola, 1992; Losey, 1995; McKinley et al., 1992; Ninnes, 1994, 1995; Prophet & Rowell, 1993; Solano-Flores & Nelson-Barber, 2001; Swift, 1992). Knowledge is often evaluated on the authority of its source, rather than the validity of its claims. To the degree that teachers and other adults are respected as authoritative sources of knowledge, students may be reluctant to raise questions or challenge adults' reasoning because this may be perceived as a sign of disrespect. As a result, some students may not practice questioning and inquiry at home and at school.

Modes of discourse in Western science requiring evidence and logic to support one's assertions, theories, or arguments are demanding for most students, especially for those whose cultural discourse patterns differ from Western science practices. For example, the separation of affect and emotion from cognition is incongruent for some cultural groups (Anderson, 1988; Atwater, 1994; Brickhouse, 1994; Deyhle & Swisher, 1997); thus, students from these groups may freely incorporate emotion to frame academic arguments (Estrin, 1993; Nelson-Barber & Estrin, 1995).

Some students do not have the discourse patterns of science, even when they have scientific understandings. Michaels and O'Connor (1990) described a situation in which a Haitian elementary student understood the concept of a balance but did not give an explanation of her mental calculation until after much probing because she did not understand that the discourse pattern of "why-because" was expected in classroom interactions. Students from cultures that do not encourage extended and detailed responses may be erroneously perceived as lacking complete and comprehensive knowledge (Lee & Fradd, 1996; Solano-Flores & Nelson-Barber, 2001). If a student's home culture values discourse that moves gradually or indirectly toward the main point, he or she may be perceived as lacking the ability to construct a sequential chain of ideas. Thus, students may be perceived as lacking scientific understandings, simply because their discourse patterns are not those of science.

Western science requires certain dispositions or habits of mind. Although some scientific values and attitudes are found in most cultures (e.g., curiosity, wonder, interest, diligence, persistence, imagination, respect toward nature), others are more characteristic of Western science. For example, Western science promotes a "critical and questioning stance" (Williams, 1994, p. 517) that calls for being skeptical, making logical arguments, criticizing others' viewpoints, and thinking independently (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996). These values and attitudes may be discontinuous with the norms of cultures that favor cooperation, social and emotional support, consensus building, and acceptance of the authority of teachers and elders (Ballenger, 1992; Hodson, 1993; Lee & Fradd, 1996; McKinley et al., 1992). Students from these cultures may have difficulty developing scientific values and attitudes, while still retaining their cultural norms (Aikenhead, 1996; Cobern & Aikenhead, 1998; Loving, 1997, 1998; O'Loughlin, 1992).

Although the distinction between the worldview of Western science and alternative views may be relatively straightforward to educated adults, children's worldviews involve a complex interaction of personal and supernatural beliefs with scientific understandings (Cobern, 1991; Hewson, 1988; Ross & Shuell, 1993). Furthermore, students from diverse backgrounds tend to express alternative worldviews more strongly than their mainstream counterparts. For example, after personally experiencing a major natural disaster, African American and Hispanic elementary students attributed the cause of the disaster to societal problems (e.g., race, crime, violence) and spiritual and supernatural forces (e.g., god, devil, or evil spirits) more strongly than did mainstream White students, who tended to give explanations in terms of natural phenomena (Lee, 1999b). The shared and public acceptance of supernatural, spiritual, or animistic accounts of nature is documented for various cultures in the United States, including Native Americans (e.g., Allen & Crawley, 1998; Kawagley, Norris-Tull, & Norris-Tull, 1998; Nelson-Barber & Estrin, 1995), African Americans and Hispanics (Atwater, 1994; Lee, 1999b), and Haitians (Ballenger, 1992). Similar results are also reported in international studies (e.g., Hewson, 1988; Jegede & Okebukola, 1992; Lawrenz & Gray, 1995; Lowe, 1995; Snively & Corsiglia, 2001).

## SCIENCE LEARNING WITH DIVERSE STUDENTS: BORDER CROSSING

As the examples in the previous section illustrate, ways of knowing in Western science and alternative ways of knowing in non-Western cultures may sometimes be discontinuous. This presents a challenge to students from these cultures in learning science (Snively & Corsiglia, 2001):

> There is a tendency in Western society to accept the evolving discoveries of WMS [Western modern science] as our best and only possible avenue for understanding how the world functions. At the same time, Western science functions as a sub-culture of Western culture (Aikenhead, 1996, 1997; Ogawa, 1995). In this way, non-Western and minority culture students of Western science may be forced to accept Western values and assumptions about political, social, economic, and ethical properties in the course of receiving information on Western science.... Thus, students from Aboriginal cultures inadvertently face a dilemma whenever they study Western science. How can science teachers enable all students to study a Western scientific way of knowing and at the same time respect and access the ideas, beliefs, and values of non-Western cultures? (p. 24).

From an anthropological perspective, learning science involves acculturating to Western science, while simultaneously integrating alternative views in students' homes and communities. Cultural transitions are critically important, and the notion of border crossing is used to describe this process (Giroux, 1992). Students cross borders from their cultural environments into the culture of Western science and school science (Aikenhead, 1996;

Aikenhead & Jegede, 1999; Cobern & Aikenhead, 1998; Costa, 1995; Maddock, 1981; Phelan et al., 1991; Pomeroy, 1994).

Students' success in school depends largely on how well they learn to negotiate the boundaries separating multiple worlds. Phelan et al. (1991) developed a model of students' multiple worlds to explore how students move from one world to another. They identified four patterns of border crossings: (1) congruent worlds support smooth transitions; (2) different worlds require transitions to be managed; (3) different worlds lead to hazardous transitions; and (4) highly discordant worlds cause students to resist transitions, which become virtually impossible. Costa (1995) applied the Phelan et al. (1991) model to 43 high school students enrolled in chemistry or earth science in two schools with diverse student groups. Costa described five patterns in the relationships between students' worlds of family and friends and their success in school and science:

- *Potential scientists:* Worlds of family and friends are congruent with worlds of both school and science.
- *"Other smart" kids:* Worlds of family and friends are congruent with world of school but inconsistent with world of science.
- *"I don't know" students:* Worlds of family and friends are inconsistent with worlds of both school and science.
- *Outsiders:* Worlds of family and friends are discordant with worlds of both school and science.
- *Inside outsiders:* Worlds of family and friends are irreconcilable with world of school but are potentially compatible with world of science (p. 316).

Border crossing between the culture of Western science and the culture of the everyday world is demanding for all students in science classes (Aikenhead, 1996; Driver et al., 1994; O'Loughlin, 1992). It may be especially difficult for students whose own cultural values and practices are, to a greater or lesser degree, discontinuous with the values and practices of Western science. At times, students may find themselves caught in conflicts between what is expected in science classes and what they experience at home and in community. If they appear too eager or willing to engage in science classes, they may find themselves estranged from home and community. If they appear reluctant to participate, they may risk marginalization from school and subsequent loss of access to learning opportunities. Although some students may successfully bridge the conflicts between home and school, others may become alienated and even actively resist learning science.

## EQUITY IN SCIENCE TEACHING

Students from diverse backgrounds acquire everyday knowledge and primary discourse in their homes, while they also learn or are presented with science disciplines and secondary discourse of science in school. From an anthropological perspective, science teaching should enable students to make smooth transitions in border crossing between their everyday cultures and the culture of Western science. The multicultural education literature and the emerging literature in science education together offer important insights about effective instruction with students from diverse backgrounds. These bodies of literature also suggest tensions between competing pedagogical approaches. Two issues emerge as central: integration of science disciplines with students' languages and cultures and a teacher-explicit to student-exploratory continuum.

### INTEGRATION OF SCIENCE DISCIPLINES WITH STUDENTS' LANGUAGES AND CULTURES

Extensive literature indicates distinct discontinuities in the communication and interactional patterns characteristic of mainstream White teachers and their students from diverse backgrounds (Au & Jordan, 1981; Ballenger, 1992; Erickson & Mohatt, 1982; Heath, 1983; Losey, 1995; McCollum, 1989; Philips, 1972). This literature emphasizes the importance of cultural congruence, indicating that when teachers and students share the same language and culture, they interact in ways that promote students' participation and engagement (Au & Kawakimi, 1994; Trueba & Wright, 1992). Whereas earlier research on culturally congruent instruction focused on teachers and students sharing the same linguistic and cultural background, recent research indicates that teachers who come from backgrounds different from those of their students can also provide effective instruction when they have an understanding of students' linguistic and cultural experiences (Au, 1980; Ballenger, 1992; Brenner, 1998; Foster, 1993; Ladson-Billings, 1994, 1995; Reyes & Pazey, 1999). Pedagogies addressing linguistic and cultural diversity have various designations, including culturally relevant, culturally appropriate, culturally responsive, culturally compatible, and culturally congruent (Gay, 2002; Ladson-Billings, 1995; Osborne, 1996; Villegas & Lucas, 2002).

Recent efforts to provide culturally congruent science instruction indicate that when linguistic and cultural experiences are used as intellectual resources, students from diverse backgrounds are able to engage in scientific practices and show significant achievement gains. For example, Native American students who were taught science using culturally relevant materials showed significantly higher achievement and more positive attitudes than did comparable students who were taught without the culturally relevant materials (Matthews & Smith, 1994). In classroom settings that capitalized on students' prior knowledge as intellectual resources, Haitian students engaged in scientific inquiry and participated in animated arguments about natural phenomena (Ballenger, 1997; Rosebery, Warren, & Conant, 1992; Warren et al., 2001).

Extending the literature on cultural congruence and culturally relevant pedagogy, Lee and Fradd (1996, 1998, 2001) proposed the notion of instructional congruence—the process of mediating academic disciplines, such as science, with students' language and culture to make the academic content accessible and meaningful for all students. Whereas work on cultural congruence and culturally relevant pedagogies has focused primarily on the interactional and discursive aspects of teaching (Gay, 2002; Villegas & Lucas, 2002) or skill area instruction such as reading or writing (e.g., Au, 1980; Delpit, 1988), instructional congruence focuses on articulating academic disciplines with students' linguistic and cultural experience to develop congruence between the two domains. The need to mediate these two domains is especially critical when they contain potentially contradictory elements. Thus, instructional congruence emphasizes the role of instruction (or educational interventions) as teachers explore the relationship between academic disciplines and students' linguistic and cultural knowledge and devise ways to link the two.

Lee and Fradd (1996, 1998, 2001; Westby, Dezale, Fradd, & Lee, 1999) implemented the framework of instructional congruence in science and literacy with English language learners. Three ethnolinguistic groups of fourth-grade elementary students and their teachers participated, including bilingual Hispanic and Haitian as well as monolingual English-speaking groups in a large school district in the southeast. At its initial phase, the research involved bilingual Hispanic and Haitian teachers who immigrated to the United States at various ages and were fluent in English and Spanish or in English and Haitian Creole. Most of the bilingual Hispanic and Haitian students were from low-SES homes (as defined by participation in free- and reduced-price lunch programs), whereas most of the monolingual English-speaking students were from middle-SES homes. Many of the bilingual Hispanic and Haitian students were newly arrived or first generation immigrants, and they were at various levels of English language proficiency. Thus, the students' languages and cultures were confounded with SES because the participating schools were located within ethnic enclaves of the communities.

Although detailed research results are reported elsewhere (Fradd, Lee, Sutman, & Saxton, 2002; Lee & Fradd, 1996, 1998, 2001; Westby et al., 1999), key issues along with examples illustrating major patterns are highlighted here. The results indicate that although establishing instructional congruence is a challenge to most teachers, it promotes students' understanding of science. The teachers realized that students' linguistic and cultural experiences were sometimes continuous with science disciplines and that these experiences could be used as intellectual resources for science learning. They used familiar experiences and culturally rooted examples and analogies to make science accessible and meaningful for their students. For example, a Hispanic teacher described how she used students' home language and culture in science instruction:

> One example is taking temperature. I know now that I have to talk about the different measurements that you can get with the thermometer. Many students know that 38° means a fever, but some of them know it as around 100°. They don't use terms like Celsius or Fahrenheit. They bring in these different experiences that we need to recognize. Another example is all of the foods we cook at home. Cooking is important in feeding a family, and they relate to that well. Hispanics do a lot of cooking in our homes. All the foods we cook at home require a lot of boiling, and they see the evaporation. So when they have lessons that involve boiling and evaporating, they have something to build on to learn science. When we do the activity on boiling, we talk about boiling *frijoles* [beans] and *arroz* [rice], things they relate to. When we measure the temperature of boiling water, we do it in both Celsius and Fahrenheit. Then they realize there are two systems of measuring the temperature. It is like speaking two languages, like bilingual.

Establishing instructional congruence presents additional challenges when science disciplines are discontinuous with students' linguistic and cultural experiences. Facing potential conflicts between students' cultural experiences and the demands of science disciplines, Hispanic teachers working with Hispanic students initially provided instruction in ways that they perceived as culturally congruent. Gradually, they made the transition to instructional congruence. For example, scientific practices require independent thought as well as teamwork and collaboration (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996, 2000). Hispanic teachers encouraged students to work individually and independently, while also valuing the group work that most students preferred. A Hispanic teacher said:

> My students like to work in groups. Hispanics tend to be social and group oriented. Parents also treat their children as babies. But we want them to do it on their own. We need to move the students beyond what they are comfortable with. Like I held my daughter by

> the hand, and then she learned to walk. The transition from being dependent to being independent in this society. And they have to do it. Then, they can do both, work independently and work with other people.

As a culminating activity of a weather unit, this teacher asked the students to make weather reports including summaries of the past week's weather and predictions for the next several days. When the teacher gave students the choice of working alone or in small groups, all preferred to work in groups of two or three. While allowing group work, the teacher told the class that everyone would participate in making presentations to the class. After all the groups made presentations, a group of two students were hesitant in giving their report. Another girl encouraged them by sharing with the class that she was nervous before her group's presentation but that everything went well. When the two students gave their report, the class applauded, and the two students smiled to the class in return. In this example, while promoting students to work collaboratively, the teacher also encouraged them to perform individually by making class presentations. The students, in turn, helped one another to learn to perform independently.

The framework of instructional congruence merges discipline-specific and diversity-oriented approaches, recognizing both the continuities and the discontinuities between science disciplines and students' backgrounds. When teachers mediate science with students' linguistic and cultural knowledge, it helps make science accessible and meaningful for students without sacrificing scientific accuracy. By emphasizing students' linguistic and cultural experiences as important for science learning, instructional congruence also has the potential to enhance their cultural identities.

## TEACHER-EXPLICIT OR STUDENT-EXPLORATORY CONTINUUM

There is a tension between mainstream pedagogical approaches and alternative approaches identified with multicultural education. The mainstream literature suggests a Deweyan or progressive approach to teaching, in which students are encouraged to ask questions and find answers on their own. Ideally, students participate in a community of scientific practices that offers rich experiences and tools to inquire and argue about natural phenomena, and through this activity they develop scientific understandings (Brown, 1992, 1994; Lehrer & Schauble, 1998; Metz, 1995, 1997; Rosebery et al., 1992; Warren et al., 2001). The premise is that students accept canonical scientific models because these models provide the best explanations for observed patterns with natural phenomena.

The multicultural education literature claims that the progressive approach favors White middle-class students. For example, Heath (1983) indicates that this approach may mirror parenting practices in White middle-class homes, thus favoring students whose home environments are culturally congruent with school pedagogy, whereas other students encounter discontinuities of discourse patterns between home and school. Gee (in press) points out that the rules of discourse students are supposed to follow are largely implicit, thus favoring the students who have already learned these rules at home.

According to the multicultural education literature, school knowledge represents the culture of power of dominant society (Banks, 1993a, 1993b; Cochran-Smith, 1995; Delpit, 1988, 1995; Ladson-Billings, 1994, 1995; Nelson-Barber & Estrin, 1995; Reyes, 1992). For students who are not from the culture of power, teachers need to provide explicit instruction about the dominant culture's rules and norms, rather than expecting students to figure out these rules on their own. Without explicit instruction, the students lack opportunities to acquire the rules. Such learning opportunities are essential because students are ultimately held accountable for knowing the rules, whether they have been taught or not.

Explicit instruction seems to imply at least two notions (Delpit, 1988; Fradd & Lee, 1999; Lee, 2001; Ninnes, 1994, 1995). First, it requires instructional scaffolding to make the transition from one set of values and practices to another explicit and visible. Teachers need to make visible students' everyday knowledge, the relationship between students' knowledge and academic tasks, and the transition from one domain to the other. Second, explicit instruction indicates teacher-directed instruction in which teachers tell students what to do or provide extensive guidance. For students who have limited experience with Western science and school science, teachers may need to provide direct instruction to build necessary concepts and skills in the context of meaningful and authentic tasks.

The cultural anthropology literature suggests a pedagogy progressing along the teacher-explicit to student-exploratory continuum for students who come from backgrounds in which questioning and inquiry are not encouraged or for students who have limited experience in Western science (Cobern & Aikenhead, 1998; Deyhle & Swisher, 1997; Fradd & Lee, 1999; McKinley et al., 1992; Prophet & Rowell, 1993; Swift, 1992). For these students, effective instructional scaffolding takes into account students' linguistic and cultural backgrounds as well as science experience. The aim is to encourage students to question and inquire without devaluing the norms and practices of their homes and communities. Through progressing along the teacher-explicit to student-exploratory continuum, teachers encourage students to take initiative and assume responsibility for their own learning. Explicit instruction in the context of authentic and meaningful tasks and activities has been advocated with students from diverse languages and cultures in literacy instruction (Au, 1998; Delpit, 1986, 1988, 1995; Jiménez & Gersten, 1999; Reyes, 1991, 1992), literature instruction (Lee, 2001), science instruction (Fradd & Lee, 1999; Lee & Fradd, 1998), and classroom discourse including science talk (Gee, 1997, in press).

*National Science Education Standards* (National Research Council, 1996) emphasizes scientific inquiry as essential to science learning and teaching. Student exploration, in which students ask questions and find answers on their own, may be the instructional goal. The issue is where to start and what to do to reach this goal for students from diverse backgrounds and levels of science experience. According to Lee and Fradd (Fradd & Lee, 1999; Fradd et al., 2002; Lee & Fradd, 2001), bilingual Hispanic teachers working with bilingual Hispanic fourth-grade elementary students suggested teacher-explicit instruction initially, followed by gradual transition to student initiative and exploration.

The Hispanic teachers noted "students' culture has a lot to do with learning science." They commented that many of their students, who were newly arrived or first-generation immigrants and from low-SES households, came from home environments where questioning and inquiry might not be promoted, as one said:

> They don't tend to question, I think. Basically, I'm speaking of Hispanic societies. You are basically told to do this and you don't question much. The American society is much freer and children are taught to question. Even as the child in your home, you know, the Hispanic households, the children better not question whatever the parent says. And they think that's something that's ingrained in their culture pretty much. They don't question much, so that science inquiry, ability of questioning, and thinking, it is limited.

The teachers also observed that many students had not received formal science instruction in earlier grades. They pointed out three main reasons why science instruction was often ignored in elementary schools, particularly for students in English to speakers of other languages (ESOL) programs: heavy emphasis on reading, writing, and mathematics; elementary teachers' lack of preparation for teaching science; and a lack of science supplies.

On both cultural and academic grounds, the teachers affirmed that the students need more explicit instruction to gradually learn to conduct inquiry on their own. Provided with effective instruction, bilingual Hispanic students learned to take the initiative, ask questions leading to scientific inquiry, and engage in scientific discourse (Fradd & Lee, 1999; Fradd et al., 2002; Lee & Fradd, 2001). The teachers observed that their students learned to engage in science inquiry over the course of the year, as one said:

> The Hispanic students, they tend to be quiet at the beginning, but then they will start opening up. The use of questioning is important in the classroom because it sets the tone with students, at least the ESOL students. I have seen a lot of growth with my students. In science, they ask questions, take the initiative, do things on their own. They have become more independent and more outspoken. As teachers, we are able to admit we don't know all the answers, and we question them and they start to question us. But they still show respect for us and see us as the authority.

The following example illustrates how a Hispanic teacher helped students progress from teacher-explicit instruction to student-exploratory inquiry. At the beginning of the year, realizing that most students were unfamiliar with using basic measurement instruments or doing investigations, the teacher gave explicit guidance about how to use equipment, do measurement, represent data in multiple formats, recognize patterns, and draw conclusions. In testing any change in the weight and volume of water during freezing, the teacher orchestrated small-group activities as part of whole-class instruction, while students completed the tasks in step-by-step unison. With limited equipment, such as scales, the teacher ensured that every student had access to the equipment, used it correctly, and learned to record accurate measurements. The teacher guided the class to construct graphs based on the class data, identify patterns, and draw valid conclusions.

As students gained experience in basic skills and concepts, the teacher moved toward more exploratory types of inquiry. In measuring temperature differences at different levels in the classroom, students recognized a pattern that temperatures were the highest near the ceiling, lower at desk level, and lowest near floor level. Based on the data from several small groups, they developed a theory that hot air rises and cool air falls. However, they observed that in one location of the classroom, the temperature at desk level was lower than the temperature at floor level. Discovering that frozen water bottles on the desks had changed the temperature of the air around the desks, students discussed exceptions due to sources of heating or cooling. Applying the theory of hot air rising and cool air falling, students discussed why they would lie on the floor during fire drills and where they would place a heater or an air conditioner in a room.

As instruction progressed, the teacher encouraged students to take the initiative in doing inquiry. In discussing temperature patterns around the world, the teacher asked the class to make some generalizations about temperatures near the equator and the poles. Students talked about temperatures around the equator being warmer than at the poles. One student stated that temperatures on the equator were warmer than anywhere else. Another disagreed by sharing his experience from his home country, Ecuador, which is actually cool. The teacher led the class to consider that elevation as well as latitude is an important factor influencing weather conditions. Then, another student pointed out that this was contradictory to their thinking that higher elevations would be warmer because they are closer to the sun compared to lower ground.

Over the course of instruction, the teacher orchestrated inquiry tasks to promote students' exploration. They learned to take the initiative in asking questions, developed theories through investigations, identified exceptions to general patterns, and engaged in debate by confirming or refuting findings using evidence. They also constructed meanings by relating the inquiry tasks and the topics of class discussion to their experiences at home or in their country of origin.

## RESEARCH AGENDA

Current research on equity has focused on pedagogical issues about science learning and teaching with students from diverse backgrounds. Much of the literature is recent, mostly from the 1990s after the release of *Science for All Americans* (American Association for the Advancement of Science, 1989). Research efforts generally involve identifying educational problems or describing instructional practices, rather than implementing intervention strategies to promote teacher effectiveness or student achievement. Research is still at the stage of conceptualizing issues that need empirical testing. Recommendations for a research agenda are offered next.

Students from diverse languages and cultures bring to the science classroom ways of knowing and talking that are sometimes discontinuous with the practices of mainstream science. Efforts need to be made to bridge the gap between students' home cultures and the culture of mainstream science. The wider the gap, the more difficult it is to bridge. When disparities abound, there is no equity if mainstream science is imposed on students who do not share its system of meanings, symbols, and practices. Similarly, there is no equity if students are not provided with opportunities to learn mainstream science.

Research needs to examine ways to integrate science disciplines with students' languages and cultures. Research generally focuses on one of these domains, while relegating the other as context. Instead, the two domains need to be addressed simultaneously to develop pedagogy that merges subject-specific and diversity-oriented approaches (e.g., Lee & Fradd, 1998; Moje et al., 2001; Warren et al., 2001). In seeking to integrate academic disciplines with students' languages and cultures, research may identify ways in which the two domains are continuous or discontinuous. Research may also examine how diverse students make sense of Western science based on their linguistic and cultural experiences and how they learn to articulate cultural norms (e.g., respect for authority or collaboration with peers) with the practices of Western science (e.g., questioning and argument). In addition, research may examine how students of diverse backgrounds achieve positive academic outcomes while maintaining their cultural identities.

Variations among diverse student groups, subgroups, and individuals need to be examined (e.g., Rodríguez, 1998b). Although common patterns may exist with an ethnolinguistic group, distinguishing it from other groups, there are also wide variations within groups based on SES, gender, English language proficiency, degree of acculturation, geographic origin, schooling experiences, and other individual factors. Information about these variations would help reduce stereotypes often associated with students of diverse backgrounds. The information would also offer insights into meeting students' learning needs based on group or individual characteristics.

To provide effective instruction for students of diverse backgrounds, teachers require knowledge of both science disciplines and students' languages and cultures. An important area of research involves how teachers resolve tensions and dilemmas between students' language and culture and science disciplines. The multicultural education literature suggests that teachers provide explicit instruction about the rules of discourse in school, rather than expect students to figure out the rules on their own (e.g., Delpit, 1988; Gee, in press; Reyes, 1992). A danger is that teachers may misinterpret explicit instruction to mean drill and practice through didactic instruction and, thus, fail to promote critical and creative thinking with diverse students. This could become yet another stereotype that can potentially limit opportunities for diverse students to learn to function competently in the mainstream (see Cohen, 2001, for a historical context). Instead, students from diverse backgrounds need to be provided with learning opportunities to explore and construct meanings based on what they bring to the learning process. At the same time, they need explicit guidance to recognize how their linguistic and cultural experiences may be continuous or discontinuous with the nature and practice of Western science. Research may examine what explicit instruction means, when and how to be explicit, and how to determine the appropriate extent of instructional support along the teacher-explicit to student-exploratory continuum.

Teacher professional development is critically important in providing effective instruction. Although the literature indicates that teacher change is a demanding process (Fennema et al., 1996; Richardson & Anders, 1994), the process may be more arduous when involving diverse students. Understanding of diversity requires that teachers assess their own identities and recognize how these may interact with student learning (Banks, 1993a, 1993b). Such analysis can lead teachers to make fundamental transformations in their beliefs and practices (Cochran-Smith, 1995; Valli, 1995). Although some teachers benefit from self-analysis and reflection as they become more aware of diversity, others become less tolerant. Because of its potentially contentious nature, some educators may simply consider the issue of language and culture "too hot to handle" (Peterson & Barnes, 1996, p. 489). Research needs to examine the process of change in teachers' knowledge, beliefs, and practices as they participate in professional development, as well as the kinds of support required for initiating and sustaining teacher change.

Research is also needed to link teacher change with student outcomes. It is important to examine how teacher change influences both students' academic achievement and cultural identities. It is equally valuable to examine how student outcomes, in turn, influence teachers' beliefs and practices. In addition, it is important to examine how different kinds of teacher knowledge are associated with different student outcomes (Carpenter, Fennema, & Franke, 1996; Kennedy, 1999). The interplay of teacher change and student outcomes may provide the most valuable insights into effective instruction and student learning.

Instructional resources need to be extended to include not only teachers but also other support systems, such as technology and community members. Technology-supported programs can offer multiple forms of representation and communication for students who are in the process of developing literacy and English-language proficiency (Shear, 1999). Technology-rich environments can also offer multiple ways of engaging in academic tasks and interacting with the teacher and peers (Krajcik et al., 1998; Marx, Blumenfeld, Krajcik, & Soloway, 1997). In addition, participation of parents and community members is valuable in incorporating students' linguistic and cultural experiences into science instruction and, in turn, making science relevant and meaningful to students' everyday lives (Hammond, 2001). Youth science programs in the community can enhance students' science learning and foster connections with the community (Barton, 1998a, 1998b).

In closing, although diverse students' linguistic and cultural experiences can serve as intellectual resources in science learning, these experiences may sometimes be discontinuous with the way science has traditionally been defined in Western modern science. Tensions and potential contradictions abound in epistemological underpinnings, curricular approaches, and instructional practices. From a cultural anthropology perspective, effective science instruction integrates science disciplines and students' languages and cultures, even when the two domains are discontinuous. The students gradually become bilingual and bicultural, as they learn to cross borders between the language and culture of Western science and their home language and culture. As research is recently emerging, further research is needed to establish a knowledge base to enable all students, including those from diverse languages and cultures, to achieve high academic standards.

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