



Being explicit about science:

Instruction in the nature of science as a multicultural approach

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ABSTRACT

Due to the growing number of students from populations underrepresented in the sciences, there is an intensified need to consider alternatives to traditional science instruction. Inquiry-based instructional approaches provide promise and possibility for engaging underrepresented students in the activities of science. However, inquiry-based instruction without culturally relevant pedagogy and instructional congruency, may not be enough to support non-mainstream students in science learning, and may even serve to challenge students' cultural ways of knowing. This conceptual paper suggests that aligning reform efforts in science education to the field of multicultural education would buttress efforts to reach underrepresented student groups in science. This includes providing culturally relevant instruction and instruction toward making the assumptions of science explicit, in particular. To this end, this paper draws from literature in multicultural education to propose that deconstructing science through instruction in NOS may support Latino, black and English language learning students in science learning.

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The purpose of this conceptual paper is to address the problem of how to support diverse groups of students and students from underrepresented populations to learn science and to gain interest in science. We will combine the theoretical viewpoints of science education and sociocultural learning theory to provide new perspectives on science instruction with diverse student groups stemming from multicultural education. To this end, we describe theoretical bodies of work and research studies providing support for embracing inquiry-based instructional approaches in science classrooms. However, we also describe how differences in language, culture, and worldviews may bring about challenges to science learning. Based on this, we suggest that inquiry-based approaches, alone, may fall short in terms of fostering opportunities for students to negotiate understandings about science. We will make the case for bolstering inquiry-based instruction with explicit instruction in nature of science (NOS) as an instructional approach, a view proposed by some researchers. However, we will push this case further, using the lens of multicultural education, where explicit instruction in NOS may facilitate a process of deconstructing science. This, in turn, may create opportunities for negotiating cultural border crossings in science learning to benefit students who are underrepresented in the sciences.

The ideas behind this conceptual paper originated in the personal classroom teaching experiences of the first author, when she taught science in a diverse urban school setting serving English language learning (ELL) students and students from multicultural backgrounds. In this setting the first author sought to bring inquiry into her classroom to engage students in science learning. Later, through reading the literature on situated cognition, she began to view participation in scientific activity, such as inquiry, as participation in scientific culture and science as a cultural way of knowing. The acknowledgement of science as culture prompted her to consider the methods of supporting children in learning across cultures, which would include everyday knowing and school science as two different cultures. She then conducted a parallel reading of the literature on sociocultural learning theory and multicultural education. Through these parallel readings, she began to look across these fields of literature, which oftentimes remain separate, and to consider moments of overlap. In this space, she drew on instructional strategies from multicultural education to enhance science teaching and learning. This includes explicit instruction as a basic tenet. The second author has conducted research related to inquiry and explicit instruction in NOS (Crawford, 2000; Schwartz & Crawford, 2004; Schwartz, Lederman, & Crawford, 2004), that provided a backdrop for infusing multicultural scaffolding into science instruction. Through this approach, we collaboratively considered the intersections of activity, context, and culture that may create moments of opportunity for scaffolding border-crossings within classroom-based science instruction.

In this paper, we argue that aligning reform efforts in science education to the field of multicultural education would buttress efforts to reach underrepresented student groups in science. To this end, we will first elaborate on establishing an understanding of science as culture and the potential and limitations of using inquiry-based instruction with underrepresented students. Next, we discuss sociolinguistic and socio-cultural boundaries and borders to science learning and the roles that language, culture, worldviews, and identity may assume. Last, we draw from the field of multicultural education to suggest how opportunities for negotiating boundary and border crossing into science may be afforded by engaging in scientific activity. This includes adopting culturally congruent instructional strategies as well using explicit instruction in NOS to deconstruct science. The following four sections develop our argument: 1) Inquiry as Participation in Scientific Culture, 2) Science Learning as Cross-Cultural Education;

3) Scaffolding for Negotiating Science Understandings; and 4) Classroom use of this Instructional Approach.

Inquiry as Participation in Scientific Culture

Science education has largely been unsuccessful in reaching ELL, Latino, Native American, black, and other non-mainstream student groups, who remain underrepresented in the field of science. As stated by William Cobern, “Science education is successful only to the extent that science can find a niche in the cognitive and socio-cultural milieu of students.” (1993, p. 57). The intent of the reform efforts advocating “science for all” (Rutherford & Ahlgren, 1990), followed by measures aimed at closing the achievement gap have worked to both open spaces and create constraints for the possibility of reaching students from underrepresented groups.

The American Association for the Advancement of Science [AAAS] (1989) initiative aimed to sweep significant change into traditional science classrooms, where instruction had mainly focused on students passively learning facts of about science. Increased attention on helping students learn how to “do science” versus just reading about science, focuses on the processes of science and how scientists do their work. Another aspect of reformed-based science involves “talking” science, which signifies appropriating scientific discourse. While the reform efforts have strived to promote active learning and highlight aspects of inquiry into mainstream of science education, there is still much debate on what exactly, constitutes scientific inquiry.

In this paper we adopt the definition of inquiry posed by the National Research Council (NRC). The NRC describes inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work” (NRC, 1996, p. 23). Inquiry is in this case consistent with the activity component of situated cognition, where the interrelated activities, context, and culture of science construct scientific knowledge (Brown, Collins, & Duguid, 1989). Inquiry is also described as, “activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23). This perspective on inquiry lends itself to framing science and the work of scientists as a community of practice, and accessing scientific knowledge through participating in scientific activities and appropriating scientific culture (Wenger, 1999).

Reforms stemming from these initiatives emphasize engaging students in *doing* science, through inquiry in active classrooms, rather than passively *learning about* it, in traditional primarily didactic classrooms. Rooted in constructivist thought, inquiry seeks to create opportunities for learners to engage in science and gain in-depth understanding by building on their previous ideas. By bringing inquiry-based science instruction into classrooms, school-based science provides the dynamic space for student participation in practices around science. Based on NRC’s recommendations (2000, p. 29), this involves the learner in the following essential activities: engages in scientifically oriented questions, gives priority to evidence in responding to questions, formulates explanations from evidence, connects explanations to scientific knowledge, and communicates and justifies findings. In this way, bringing inquiry into science classrooms would better merge school science with the work of scientists, in ways different from traditional instruction. Moreover, inquiry may create the space to interconnect students’ everyday experiences, school science, and the scientific enterprise.

A number of research studies in classrooms have shown the practice of using inquiry-based strategies to have positive results with diverse and underrepresented students (Rosebery,

Warren, & Conant, 1992; Amaral, Garrison, & Klentschy, 2002; Lee, Deaktor, Hart, Cuevas, & Enders, 2005; Cuevas, Lee, Hart, & Deaktor, 2005; Lee, Buxton, Lewis, & LeRoy, 2006). For example, Rosebery et al. (1992) designed an inquiry-based experiment for English language learning (ELL) students and measured the effects of this intervention on student science learning and language development. The researchers found that most students demonstrated the ability to talk scientifically in their native languages through an inquiry-based instructional approach. Amaral et al. (2002) studied the effects of an inquiry-based curriculum on the academic achievement of ELL students from mostly Latino backgrounds. Findings demonstrated an increase in student achievement in all domains of testing related to an increase in time exposed to the curriculum.

Though these studies demonstrate promise, certain students groups continue to be underrepresented in high school science classrooms, science-related majors in universities, and science-related careers in the U.S. (Lee & Luykx, 2006). This trend persists despite extensive education reform efforts aimed at improving science achievement on both a national and international scale. Reasons attributed to the underrepresentation of population groups in the sciences are many and complex. Recent efforts to close the achievement gap and raise the science aptitude of students have mainly focused on increasing accountability and evaluation measures (Settlage & Meadows, 2001). Without directing greater attention to students' actual experiences in school science and how science may or may not align with students' diverse racial, cultural, and linguistic backgrounds and understandings, these student groups will likely remain underrepresented in the sciences.

While inquiry-based instruction may afford increased opportunities for engaging all kinds of students in science learning, there is a need to better conceptualize the challenges that students continue to face. While anthropological researchers point to a divide between students' ways of knowing and schooling (Foley, 1990; Lipka, Mohatt, & the Ciulistet Group, 1998), sociolinguists point to the differences between everyday ways of knowing and science (Warren, Ballenger, Ogonowski, Rosebery, Hudicourt-Barnes, 2001). Still other educational researchers point to the disconnect between school science activities and the scientific enterprise (Brown et al., 1989). Inquiry, by contrast seeks to bridge these domains.

The approach we propose includes viewing science as culture; and drawing from the field of multicultural education to suggest instructional approaches that support students in negotiating their understandings of science. The next section will unpack our theoretical approach and describe our rationale. To this end, we will first utilize sociocultural theory in science education to highlight the cross-cultural challenges of science learning. We will then suggest how instructional strategies drawn from the field of multicultural education and infused into science teaching and learning may support students in navigating the cultural divides between their everyday life-worlds, school, and school science.

Learning Science as Cross-Cultural Education

Science education literature has contributed to a fragmented understanding of how the cultures of science, school, and students converge in the space of school science learning. By combining these perspectives, science learning would entail a student engaging in the culture of science within the culture of school, a perspective largely not addressed. This might seem an incommensurable project, without greater recognition for culture as dynamic, fluid, and constantly shifting (Gutierrez & Rogoff, 2003). In framing science learning as multi-tiered

interaction between students, schools, and the scientific enterprise, a greater focus can be directed toward what schools and students bring to this process. This is significant, in order to view learning as a sociocultural and dynamic exchange of differing ways of knowing. In this way, the intersection of the cultures of students, schools, and inquiry-based science become moments of opportunity for negotiation.

Viewing science as culture creates the space for examining science learning, and inquiry, as a borderland of cultural interaction. As Driver, Asoko, Leach, Mortimer, and Scott (1996) state, “the view of scientific knowledge as socially constructed and validated... means that learning science involves being initiated into scientific ways of knowing” (p. 6). Moreover, science learning becomes a “process of enculturation rather than discovery” (p.11). Along these lines, learning science becomes an appropriation of the activities, context, and culture of science (Brown et al., 1989). Interestingly, recognition of the cultural components and norms of science, such as argumentation (Lee, 2003), may offer perspective for examining the challenges that underrepresented students face in learning science.

For example, interrelated linguistic and cultural challenges to science learning may persist despite innovative instructional approaches that may engage students in the activities of science. In essence, to certain student groups, school science becomes a form of cross-cultural education. To these students, “science is a second culture, in much the same ways as American educators speak of English as a second language for some students” (Cobern, 1993, p. 58). From the perspective of Ogawa on classroom educators in Japan:

Science, the product of western modernization, should be taught in the context of a foreign culture in school science in nonwestern society. On the basis of this position, science teachers need not only know the western science itself but also be aware of the traditional and scientific ways of thinking, and views of nature. (Ogawa in Cobern, 1993, p. 56)

Viewing science as a cultural way of knowing acknowledges that it is laden with cultural understandings, interpretations, and a language of its own. For example, “Whenever pupils enter the world of school science, it soon becomes evident that science too is another culture with which s/he has to interact, bringing with him/her the other baggage of cultures s/he already carries” (Jegede & Aikenhead, 1999, p. 45). For example, science learning may become particularly challenging when the cultural practices of the scientific community may or may not align with the cultural understandings of students (Lee, 2003). These understandings include language and culture and play an integral part in shaping student identity and worldviews, or frameworks of ideas and beliefs through which individuals interpret the world and interact with it (Cobern, 1993). These concerns translate to classrooms serving students underrepresented in the sciences. Barton & Tan (2009) describe this as the conflicting nature of school science and the everyday understandings of students from nondominant cultures. In this case, school science, becomes yet another cultural border for students to cross, amongst the other challenges contributing toward the differential achievement of students in schools (Aikenhead, 1996).

Sociocultural perspectives are thus essential to understanding the challenges of science learning for underrepresented students and the moments of possibility in achieving cross-cultural understanding. Sociocultural theory opens the space for examining challenges to science learning as being bounded by cultural boundaries and borders. Erickson (1993/1996) refers to the ability of students to negotiate differences in cultural understandings in schooling by moving through cultural borderlands, or the space of negotiating cultural understandings, by way of traversable *boundaries* or more rigid *borders*. Whereas boundaries refer to cultural differences,

borders are social constructs across which power is exercised. Borders comprised of epistemological differences create deeper divides between cultures than communicative patterns. Moreover, power differentials set by borders in schooling and teacher-centered instructional approaches may limit the negotiation of cultural differences and understandings and may bring about resistance to learning. We apply these same constructs to describe challenges to science learning for diverse student groups. Whereas we frame the differences in cultural communicative patterns as boundaries to science learning, we delineate deeper epistemological differences as borders to science learning. We suggest how infusing multicultural education strategies into science classrooms may present opportunities for negotiating boundary and border crossings into science. Moreover, we advocate for explicit instruction in NOS as an integral component of science instruction and part and parcel of a multicultural approach.

Scaffolding for Negotiating Science Understandings

Negotiating Boundaries

Several bodies of work relate to language-based limitations for underrepresented students in science learning. This research represents multiple perspectives on the relationality of students, their linguistic abilities, and science, in light of students' participation in scientific investigations. For example, research related to the Chèche Konnen project directs attention to science learning through the use of students' native and everyday languages (Rosebery et al., 1992; Warren et al., 2001). Other research directs attention to English language acquisition through participation in inquiry-based activities (Stoddart, Pinal, Latzke & Canaday, 2000). However, Okhee Lee's work additionally considers the linguistic and cultural support needed by students engaged in inquiry-based science. The principles introduced through her work reach beyond instructional approaches for ELL students, but rather are inclusive of teaching practices to help all students succeed (Ladson-Billings, 1995).

Lee and Fradd (1998) contend that science learning is not accessible to non-mainstream students through inquiry without further instructional support. "Traditionally, science has been taught with the expectation that students will understand and learn when teachers present the content in scientifically appropriate ways... little consideration [has been given] to students' literacy, language, and cultural understanding" (p. 12). Lee (2003) further argues that not only do students need linguistic scaffolding, but students' cultural norms must also be brought into inquiry-based instructional settings:

although scientific inquiry is a challenge for most students, 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. 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. (p. 466)

In this sense, inquiry-based instruction must be framed in an accessible way to underrepresented and non-mainstream students, and cannot alone be expected to assist students in science learning. Drawing from the field of multicultural education may support students in navigating some of the boundaries established by linguistic and cultural differences.

Lee and Fradd's (1998) seminal work in considering non-mainstream students' interaction with language and the culture of science provides a framework for increasing the accessibility of science instruction. Rather than assuming students' appropriation of language

and scientific understandings through participation in scientific activities, the researchers direct attention toward modifying instruction to fit students' existing tools for mediating learning. They build on the construct of *cultural congruency*, where instructional methods are aligned with students' cultural understandings and uses of language, to offer a framework for *instructional congruency* in science education. Lee (2004) explains that while cultural congruency entails "teachers integrat[ing] academic disciplines with students' linguistic and cultural experiences to promote academic achievement" (p. 66), instructional congruency applies the construct of cultural congruency to a specific area of instruction, such as science education. In Lee's words, "the instructional congruence framework maintains that effective subject area instruction should combine consideration of students' cultural and linguistic experiences with attention to the specific demands of academic disciplines" (2004, p. 67).

In a later work, Luykx and Lee (2007) introduce the instructional congruency framework. This framework serves as a useful tool for evaluating the cultural congruency of science instruction by seeking the inclusion of the following components in science instruction: 1) a sharing of scientific authority, 2) a diversity of cultural experiences and materials, 3) the use of students' home languages in classrooms, and 4) the use of linguistic scaffolding to enhance meaning. The researchers describe:

The instructional congruence framework holds that academic content, as well as the cognitive and discursive practices associated with particular academic disciplines, are made more accessible and meaningful for students when they are purposefully mediated by students' linguistic and cultural experiences. As a guiding principle for pedagogical practice, instructional congruence aims to help students acquire scientific understandings, inquiry practices, and discourse by taking into account the relation of these three domains to students' home culture and language, and by devising instructional strategies that address both the discontinuities and the continuities between the two broader bodies of knowledge (i.e., school science and students' prior linguistic and cultural knowledge). (Luykx & Lee, 2007, p. 425)

In this way, this framework for instruction combines the mediation of scientific and cultural understandings with students' use of home language to gain understanding. Moreover, it entails a student-centered approach to instruction, where students share the process of engaging in constructing scientific explanations.

Together, the components of the instructional congruency framework align science reform efforts toward inquiry-based instruction with research in both science and multicultural education. Primarily, encouraging the *sharing of scientific authority* entails a shift from traditional teacher-centered instruction to a student-centered approach (Crawford, 2000). In this shift, teachers become learning facilitators rather than the primary sources of knowledge. The sharing of scientific authority is also an integral part of inquiry-based instruction. In this way, the instructional congruency framework encourages the use of inquiry. Further components of the framework align with research in multicultural education. For example, bringing *diverse cultural experiences and materials* into a classroom invites and validates students' cultural backgrounds. This aligns with a "funds of knowledge" approach (Gonzalez et al., 2005). Moreover, encouraging *the use of home languages* in science classrooms reflects the research-based findings of the Chèche Konnen Project described above. In using home language, or everyday language, during instruction, students are not detracted from content-matter instruction (Banks, 1996, Brown & Ryoo, 2008; Nieto, 2004). This is particularly relevant to all students when recognizing the language of science as a language apart from everyday language (Lemke,

1990; Warren et al., 2001). Research on English language development supports *using linguistic scaffolding to enhance meaning* (Cummins, 2000). Moreover, linguistic scaffolding could include making language switching codes between science and everyday language explicit to other students. For example, teachers would ask students, “how would you say that in scientific terms?” In this case, in making the language of science explicit, teachers would support students in making boundary crossings into science by learning when to use scientific language apart from everyday language. With the aid of linguistic scaffolding, students would be supported in learning both science and language. In this way, the framework for instructional congruency combines the mediation of scientific and cultural understandings with students’ use of home language to negotiate boundaries in science.

Similarly to Lipka et al.’s (1998) work with Yup’ik students in Alaska, the instructional congruence approach enacts a “both/and” approach rather than an “either/or” approach. Through cultural validation and with the addition of language-based support, science learning can be likened to negotiating a “boundary,” per Erickson’s (1997) use of the term. In this sense, instructional congruency strategies may integrate student cultural artifacts into science instruction and assist non-mainstream students traversing differences in language and culture. This instructional approach presents a significant point of departure from traditional instruction and would serve to bolster inquiry-based instruction, as described above. Nonetheless, the instructional congruency framework falls short of considering more deeply set cultural and worldview differences. While the framework may support students in negotiating linguistic and cultural boundaries, it does not address borders to science that may be established by differences in worldviews and how these worldviews are positioned in relation to dominant understandings about science. The next subsection discusses explicit instruction about science *itself* as a pathway toward extending a “both/and” instructional approach to support students in gaining understandings in science while maintaining their own cultural identities.

Negotiating Borders

Sociocultural views of science education extend the notion of cultural congruency to include epistemic and worldview perspectives. Science instruction may become culturally *incongruent* for non-mainstream students with epistemic differences and contradicting worldviews (Aikenhead, 1996, 2001; Cobern, 1993; Jegede & Aikenhead, 1999; Ogawa, 1995). These cultural differences potentially constitute borders to science education and are rooted in the lack of opportunities to negotiate understandings, power differentials, and identity. Students that experience challenges to their world-views, or everyday and culturally-based understandings of the world as a result of science instruction may respond with resistance to science learning.

As Jegede and Aikenhead (1999) describe, “for a majority of students, science teaching is experienced as an attempt to assimilate them” (p. 48). For example, even instructional approaches through inquiry have mostly neglected science learning from students’ perspectives. Though inquiry-based instruction seeks to establish mechanisms through which the learner can gradually become a part of the school science community and ultimately, the scientific community should they choose, the milieu of the learner is not addressed in this process. While students’ participation would assist them in acquiring scientific knowledge, skills, and understanding as they engage with the scientific community, this relationship is unidirectional. The learner is brought *into* a community, rather than given the opportunity to establish a reciprocal relationship of shared understanding. Moreover, little is known about the process of negotiating scientific understanding from the perspective of the learner. Though inquiry builds

from student background understandings, it does not offer the space to address students' cultural understandings and how they may or may not intersect with the culture of science. In this sense, inquiry-based instruction must be framed in an accessible way to students, and cannot alone be expected to assist students in science learning. For these students in particular, science learning does not entail cultural congruency in deeper sense where epistemic underpinnings and worldviews align. This is because "a cultural perspective recognizes conventional science teaching as *an attempt* at enculturation or assimilation—cultural transmission that supports or replaces a person's life-world subcultures respectively" (Aikenhead, 1996, p. 20).

Similarly to literature on cultural borders, where power differentials are at play in a borderland interaction (Erickson, 1997), Aikenhead (1996) draws attention to cultural borderlands in science learning. However, he does not draw the distinction between traversable boundaries and rigid borders in his work. Rather, Aikenhead frames the rigidity of the border in science education based on its relationality to the learner:

If the subculture of science generally harmonizes with a student's life-world culture, science instruction will tend to support the student's view of the world ('enculturation'). On the other hand, if the subculture of science is generally at odds with a student's life-world culture, science instruction will tend to disrupt the student's view of the world by trying to replace it or marginalize it ('assimilation'). (1996, p. 5)

Aikenhead also acknowledges that science learning is more accessible to student groups whose cultural ways of knowing align with scientific culture. More specifically, science learning is implicated in Western ways of knowing, an already accepted cultural norm for many mainstream students. Along these lines, science learning becomes an additional challenge to the cultural ways of knowing of many non-mainstream students. Moreover, science education becomes a border when it becomes "subtractive," or marginalizes the world-views of students in relation to Western modern science. This is especially evident in science instruction for indigenous groups (Cobern & Loving, 2000). Researchers propose several suggestions for easing the cultural border crossings of students in science education.

For example, Aikenhead (1996) emphasizes the importance of teachers supporting students in border-crossings into science. This includes teachers' acknowledgement of the differences between science and the life-worlds of their students:

Science educators, Western and non-Western, need to recognize the inherent border crossings between students' life-world subcultures and the subculture of science, and that we need to develop curriculum and instruction with these border crossings explicitly in mind, before the science curriculum can be accessible to most students. (p. 2)

To this end, he combines the work of several anthropological theorists to point to the role of educators as "tour-guides" into the world of science in relation to their students, who may have varying degrees of border-crossings. A teacher may act as a coaching apprentice, travel-agent culture broker, or tour-guide to a student who is experiencing border crossing experiences into science.

Jegede and Aikenhead (1999) describe collateral learning, where "conflicting schemata [related to science learning are] held simultaneously in long term memory" (p. 52), as a function of successful border-crossing. Rather than undergoing enculturation and assimilating to views of science, collateral learners adapt different responses to the epistemological challenges of science. These learners engage in science learning through anthropological approaches, where science is studied but may or may not be incorporated into their cultural ways of thinking. Alternatively, students may undergo autonomous acculturation, where scientific and cultural ways of thinking

coexist and are not disputed. In either case, a negotiation of cultural identity does not become part of the process of science learning. Identity and science learning remain separated. Moreover, students do not cope with challenges to cultural understandings by actively resisting science learning in these scenarios. Given support toward recognizing the cultural components of science and adapting a “both/and” approach, border crossings may become accessible to students with worldviews that differ from those of science. These students may include girls, Latino, Native American, and black students, who remain underrepresented in sciences, as well as ELL students.

Though both traditional and alternative forms of science instruction in schools are implicated in learning Western modern science, inquiry may engage students in the activities of science. Because activity reflects the cultural practices of a community, an inquiry approach using authentic investigation could involve students in scientific culture. This, in turn, may increase the accessibility of science for these students. Inquiry would thus afford greater opportunities for the negotiation of epistemic stances and worldviews as related to Western modern science.

Nonetheless, the negotiation of understandings cannot be accomplished through inquiry alone, as described above. Lee (2003) suggests explicit instruction as a pathway towards both boundary and border crossings in science education. She insists “ELL students need *explicit* guidance to recognize how their linguistic and cultural experiences may be continuous or discontinuous with *the nature and practice of Western science* [italics added]” (p. 481). A basic tenet of multicultural education, explicit instruction draws students’ attention to code-switching. For example, instruction toward recognizing the shift between everyday language and scientific discourse would help make linguistic codes explicit. In this way, students would be supported in recognizing everyday language apart from scientific discourse towards crossing a boundary into science and learning when to use scientific language.

Other multicultural education theorists uphold the need for explicitness in instruction towards making content-matter learning accessible for students and border-crossings possible (Banks, 1996; Erickson, 1997; Ladson-Billings, 1995). However, moving educators towards a deeper explicitness in science instruction would include mapping the assumptions of science. This would entail an intensification of James Banks’ platform for a critical rereading of curriculum in multicultural education (Banks, 1996). Rather than focusing solely on transformative knowledge, or knowledge that empowers students, explicit instruction in science would include learning about knowledge frameworks. While Banks does suggest an interrogation of “how knowledge is created and how it reflects the experiences, values, and perspectives of its creators” (p. 339), he does not go beyond this to consider comparative frameworks for knowledge construction in science, and how students’ ways of knowing may or may not connect.

Making the assumptions of science explicit may facilitate border crossings for students. This is because the subculture of school and schooling may differ from students’ home cultures. These cultural differences may be particularly exacerbated in science instruction, where not only the subculture of school may differ from students’ home cultures, but science may remain a subculture apart. Making science explicit through instruction is thus particularly relevant for students whose worldviews and subcultures differ from the cultural values of school-based science.

Lederman (2004) offers an instructional approach that may serve to frame science and its culture explicitly for diverse student groups. Though Lederman’s work does not address cultural

differences in science learning, he advocates for combining inquiry-based instruction with explicit instruction in NOS. Lederman proposes supplementing science instruction with understandings of NOS. Specifically, he contends that:

Scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived at least partially from observations of the natural world), subjective (theory-laden, involves individual or group interpretation), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded (influenced by the society/culture in which science is practiced). (Lederman, 2004, p. 304)

Explicit instruction in NOS would include deconstructing science and framing science content matter within its epistemological framework. For example, instruction in NOS would reframe science as a social process of knowledge production rather than a body of factual information. Framing science within its epistemological assumptions, through an instructional approach including inquiry, instructional congruency, and explicit instruction in NOS, would provide students with tools for the exploration of science on its own terms. These instructional approaches are also intertwined. Rather than implementing science instruction that challenges, marginalizes, and is “subtractive” to students’ epistemic stances and worldviews, greater instructional congruency can be met with instructional approaches that provide opportunities for deconstructing science and the negotiation of worldviews. Inquiry, combined with instructional congruency and explicit instruction in NOS, would thus engage students in the activities of science framed by the assumptions of science.

An instructional emphasis on NOS may facilitate students’ abilities to navigate between their own understandings, school science, and the scientific enterprise (see Figure 1 below). Instructional congruency, for example, uses linguistic scaffolding to increase the accessibility of science during instruction. This approach, combined with NOS, would also frame the culture, norms, and assumptions of science. Explicit instruction in NOS offers a pathway for explaining

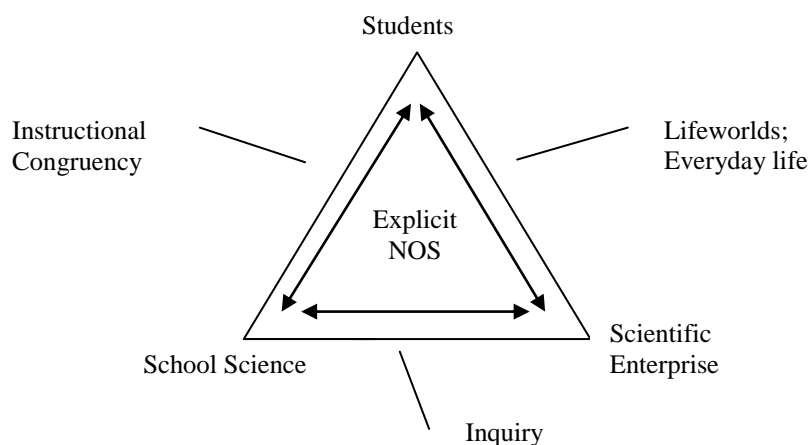


Figure 1. Instructionally congruent inquiry-based instruction combined with explicit guidance in NOS

how science influences day to day life and its potential limitations. Inquiry offers an instructional approach to begin to bridge between school science and the activities, context, and culture of the scientific enterprise. The possibilities and limitations of these scientific ways of knowing can be made possible by explicit instruction in NOS. Together, instructionally

congruent inquiry-based instruction combined with explicit instruction in NOS, may provide important opportunities for non-mainstream students in negotiating differences between their lifeworlds, school science, and the scientific enterprise. Along the lines of collateral learning and a “both/and” instructional approach, this combined approach does not seek to challenge students’ ways of knowing, but rather, provide tools for better understanding scientific ways of knowing.

This combined instructional approach may increase the accessibility of science and offer affordances to students challenged by border-crossings into science. For example, explicitness about scientific knowledge being “*subject to change*” may facilitate student understanding of the scientific process of knowledge production. For example, a teacher can explain draw on examples that demonstrate changes in theories. This understanding may offset views of science as a fixed “truth” to accept and provide opportunities for students to negotiate understandings about science as an evolving field in which they, too, can participate. Explicitness about science being “*based on and/or derived at least partially from observations of the natural world*” may in turn ground scientific learning in everyday life situations for students. This would provide space for student agency as active participants observing and making sense of the world around them. Explicitness about science being “*theory-laden, involves individual or group interpretation*” may demystify power-relations in scientific knowledge construction. Within an instructional setting, this approach may invite a process of negotiating and accepting alternative understandings. Explicitness about science involving the “*invention of explanations*” may foster the participation of diverse student groups. Rather than challenging students’ cultural ways of knowing, this approach would boost student agency in making sense of science *and* the natural world as they attempt to make their own explanations. Finally, explicitness about science being “*socially and culturally embedded*” may help students frame science as a cultural way of knowing with its own language, processes, and customs. This in turn, may help bolster student agency to participate in science, while retaining cultural understandings and ways of knowing. Part of this includes demystifying how science is constructed and repositioning science as another way of knowing. This approach acknowledges that there are different cultural ways of knowing, science being one of them. The following section of this paper considers actualizing this instructional approach in classrooms serving diverse student groups.

Classroom Use of this Instructional Approach

Science education researchers provide an extensive literature base related to enhancing inquiry-based instruction with NOS (Lederman, 2004; Schwartz, Lederman, & Crawford, 2004). The implementation of this instructional approach aligns with reforms in science education, where students are engaged in inquiry and the activities of science. Lederman (2004) explains:

Explicit attention to NOS simply means that the various aspects of NOS are made “visible” within instruction through reflective discussions with students about the practice of science. As much as possible, these discussions should be student centered with the various characteristics of science and scientific knowledge elicited from students rather than communicated in a didactic manner. (p. 312)

In this way, the actualization of this instructional approach already assumes a student-centered learning environment driven by student questioning. This includes repositioning the teacher as a facilitator of learning rather than a source of knowledge (Crawford, 2000).

Explicit instruction in NOS can also integrate with and enhance multicultural education practices (see Table 1). Within the instructional congruency framework, an inquiry-based instructional approach also already assumes a sharing of scientific authority and student-centered learning. Moreover, linguistic scaffolding to enhance meaning and the use of native and everyday language in the classroom increases the accessibility of science content-matter instruction. Greater context and relevancy are created by drawing on students' diverse cultural experiences and materials. These practices combined, focus on preparing students to appropriate scientific understandings. The added component of explicit instruction in NOS introduces the cultural components of science and frames it within its own assumptions. This instructional approach may help support students in accommodating competing worldviews and understandings toward maintaining a collateral, rather than challenged, worldview.

Table 1. Instructional Congruency Enhanced with NOS

| Instructional Approach | Features |
|---|--|
| 1. Sharing of scientific authority | Student-centered approach; assumed by inquiry |
| 2. Linguistic scaffolding | Increases accessibility of content-matter |
| 3. Use of everyday language in the classroom | Increases accessibility of content-matter |
| 4. Use of diverse cultural experiences and materials | Draws on students' everyday lives and lifeworlds |
| 5. <i>Explicit instruction in NOS</i> | <i>Introduces cultural components of science and frames science within its assumptions</i> |

Glimpses of the implementation of this combined instructional approach can be drawn from early findings related to a recent case study investigation in an urban 5th grade bilingual classroom. In this classroom, the teacher, Monica, who had already adopted instructionally congruent approaches to her teaching, was implementing the Fossil Finders Project, an inquiry-based instructional unit focused on investigating the environment of the past using fossils. Monica's students, who were all from Latino backgrounds, observed, identified, and measured fossils to gather data. They then entered these data into an online database, where they would be able to see the congregate data of their classroom as well as the data of other schools involved in the project. Using this data, the students made inferences about their local environment during the Devonian period. During the implementation of the curriculum, Monica made repeated references to how students were modeling the authentic activities of scientists. The following transcript segment illustrates how Monica embedded explicit components of NOS into inquiry-based instruction that also had components of instructional congruency. In this excerpt she uses the National Academy of Sciences (1998) Tricky Tracks lesson, which is an introductory part of the Fossil Finders Curriculum Unit.

Monica: [About the Tricky Tracks activity] *We don't have any evidence that shows that the tracks took place at the same time. Who here has a dog?*

Students: [A few murmurs]

Monica: *Okay. Did you ever take your dog walking and all the sudden they want to sniff and sniff and sniff and you're like, oh, another dog's been here?*

Raul: *Yeah*

Monica: *Could it be possible that one dinosaur came, walked around, took off and left the big tracks, let's say, and then maybe the little dinosaur came and sniffed around the tracks of the big dinosaur... and then flew away?*

....

Students: *[Murmuring]*

Monica: *That could be another take on what's happening. Or they both could have been walking, they could have been walking dinosaurs both of them and maybe that, the how do we say it, the petro... how do we say it?*

Students: *[overlapping] Petroteronodon...*

Monica: *Monica: Flew down and got the little dinosaur and took him away!*

Researcher: *It's actually Pterow-daactyl.*

Monica: *Oh, that's how you say it?*

Students: *[Repeating pronunciation]*

Monica: *Thank you, Researcher. [To students] Miss Monica doesn't want to misinform you*

Monica: *But couldn't that have happened? Both dinosaurs heading toward the same place? The same food source? Maybe there's water there? There's vegetation...? That's something else that could have taken place.*

Monica: *That's what I wanted you to see... different perspectives, different ways that you can view the Tricky Tracks, okay? And I want you to think back, do you remember... a [recent] question [we had] that said: "if scientists all have the same facts, how come they have different theories on what may have happened to dinosaurs?"...*

Monica: *If they all have the same facts, why do they have different theories, remember we said it was different stories? This is the perfect example of how we can have the Tricky Tracks, the same facts, the same observation, but yet we are making different inferences, right? Different takes on what could have been.*

In this brief exchange, Monica demonstrates cultural congruency and explicitness about the nature of science. First, Monica references the need for evidence to construct an explanation. She states “We don’t have any evidence that shows that the tracks took place at the same time.” She then proceeds to tie this concept to students’ knowledge and understanding about dogs. For example, in building on an example of how dogs may stop to sniff, she drew on students’ everyday lives. Monica shares authority, albeit not particularly scientific, when trying to pronounce the word “pterodactyl.” In this way, she welcomed the participant observer approach that we, as researchers, took on in her classroom. Monica then proceeds to recall some of the possible explanations that students had come up with about the Tricky Tracks scenario. She refers to the multiple possible explanations of the Tricky Tracks activity as “different perspectives, different ways you can view [them]” and “different takes on what could have been.” This relates to the interpretive and creative components of NOS. She also points out that

the activity relates to a question that they'd already seen about why scientists have different theories. To tie scaffold the concept of scientific theories, Monica calls them "stories." In this way, students can better connect to what is being discussed. These early findings support some aspects of this instructional approach, implemented in a staggered fashion. However, they do not fully illustrate a combination of all three components simultaneously.

Nonetheless, early findings also suggest that students' views on science were impacted by this instructional approach. Following instruction about what scientists do and their relationship to the Fossil Finders project, the students were eager to meet an actual scientist. The teacher invited a paleontologist into the classroom to answer student questions about what it is like to be a scientist and how scientists do science. Students prepared questions for the visiting scientist ahead of time and interviewed her during her visit. Through this experience, school science, the scientific enterprise, and students' lifeworlds were merged. In this way, these students were able to access scientific knowledge and culture, as well as a scientific community of practice (Wenger, 1999). In a conversation with Alyssa, a Latina ELL student from Puerto Rico, the first author asked her about meeting the scientist may have changed her views on science.

Researcher: What was it like meeting a scientist?

Alyssa: It was really cool because I wanted to meet a scientist

Researcher: Okay, and why did you want to meet a scientist

Alyssa: Cause I was wondering what they did and about how they felt... and I got to know what they did and what they felt

Researcher: Okay, does it change what you think about science?

Alyssa: Yes.

Researcher: How?

Alyssa: Cause it makes me more interested in science and that I get to get like more... [long pause].

Researcher: Puede ser en español si quieres [translation: It can be in Spanish if you'd like]

Alyssa: Mas [granas] sobre fossils [translation: More about fossils]

Researcher: Okay, and did you think that science was different last time or before you met the scientist?

Alyssa: Mmm hmm...

Researcher: And, what did you think science was like?

I thought, before we was working on the fossils, I thought it was different,

Alyssa: like just reading in the book. And, like, when we got the fossils, it wouldn't be much fun... cause we could really see the stuff. But, we actually got to and then it was fun!

Researcher: Okay, and what did you learn about what scientists do when you met the scientist?

Alyssa: I learned that they travel and that they had a lot of school and that they had a looong, that they had to go to school to become a scientist

In this conversation, Alyssa reflects on how her views on science had changed after participating in scientific activities and meeting a scientist. The instructionally congruent components of the curriculum increased the accessibility of scientific content matter. For example, the ability to use everyday and native language, as demonstrated in the interview, provided Alyssa the space to

learn both science and language. Further, explicit instruction in NOS and authentic participation in scientific activity, which included meeting with an actual scientist, helped reshape Alyssa's views on science. Alyssa, for example, is interested in learning about what scientists *did* and how they *felt*. Through participation in inquiry, Alyssa began to view science as fun, rather than something that you do from a book. Alyssa also claims to have learned more about how scientists feel. When the scientist came to visit, she described her job with a lot of enthusiasm. This may perhaps as well shifted Alyssa's views on science. Alyssa's example points to a few areas of research and areas in which gaps in the research still exist. While several studies focus on different uses of language in science learning and the need for explicit transitioning between home language and scientific discourse (Brown & Ryoo, 2008), limited research has been conducted on how instructional approaches may support underrepresented students in mediating between cultural understandings and science.

Conclusions

From critically reviewing the literature the authors propose an integrated research-based approach to supporting underrepresented students in learning science. Contrary to reforms that differentiate between *learning* science and learning *about* science, we believe that an instructional approach is needed that does *both*. While learning science would entail engaging in similar activities of scientists in the reduced form of school science, learning about science would entail learning how these activities and science content are framed by NOS. While inquiry-based approaches afford greater opportunities for establishing greater relevancy in learning experiences, *instructionally congruent inquiry coupled with explicit guidance in NOS* may help frame science as a cultural way of knowing and provide students with opportunities to negotiate identities in relation to science. Combining these instructional approaches may provide promise and possibility for reaching students in science education, and underrepresented student groups, in particular.

Our call for explicit instruction in NOS aligns with that of Lederman (2004), but we combine this with the call of multicultural education theorists for instructional approaches that facilitate border-crossings. Making nature of science explicit throughout instruction is thus particularly relevant for students whose worldviews and subcultures differ from the cultural values of school-based science. Bolstering science teaching with explicit instruction in NOS may support underrepresented and ELL students in better framing their understandings of science and negotiating cultural border crossings. Situating science within its epistemological assumptions would provide underrepresented and ELL students with tools for the exploration of science on its own terms in relation to their own cultural understandings.

Beyond making nature of science explicit, an effort to support students in making linguistic and cultural boundary and border-crossings in science learning would recognize science as a cultural way of knowing, adopting instructionally congruent learning strategies, and deconstructing science through explicit instruction in NOS. While inquiry-based approaches afford opportunities for establishing greater relevancy in learning experiences, *instructionally congruent inquiry coupled with explicit guidance in NOS* may help frame science as cultural way of knowing and provide students with opportunities to negotiate identities in relation to science. Combining these instructional approaches may provide promise and possibility for reaching students in science education, and underrepresented student groups, in particular.

For example, students can become active participants in the activities of science and a part of the knowledge construction process. Monica framed the work of scientists as careful and accurate, but still susceptible to human error. As a result, students rechecked their measurements and were assertive about being right when Monica double-checked their work. They asked the visiting scientist to explain how she was certain about different types of fossils. The students themselves also became the experts on the types of fossils in their samples and deferred to each other for expertise. However, they directed the questions that they could not answer to the visiting scientist. These students fully participated in guided inquiry, framed by explicit instruction in NOS and instructionally congruent practice.

Further research is needed to learn how teachers can give students from diverse cultural backgrounds in multicultural classrooms the needed support in learning science. While *explicit instruction in NOS coupled with culturally congruent inquiry-based instruction* may provide students with a means to negotiate understandings in science, there is currently no empirical evidence related to the use of this instructional approach with underrepresented students. Further investigation is needed to understand how explicit instruction in NOS integrated into inquiry-based instruction with instructional congruency may afford underrepresented and ELL student groups greater connections to science learning.

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