Partnering Through Science: Developing Linguistic Insight to Address Educational Inequality for Culturally and Linguistically Diverse Students in U.S. STEM Education

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Abstract

Linguists must build and strengthen research partnerships with science, technology, engineering, and mathematics (STEM) educators to further investigate linguistic and cultural diversity and academic inequality in STEM education in the U.S. We review key issues and themes from literature on the role of language in U.S. STEM education and the linguistic and ideological roots of barriers to STEM achievement for culturally and linguistically diverse students. We assess ways that linguists have engaged with educators and teachers, learning from humanities- and social science-based partnerships and adapting them to STEM contexts. We then examine specific and significant challenges that culturally and linguistically diverse student populations in STEM areas often face, with a focus on structural, sociocultural, and ideological barriers. Finally, we advocate for forging partnerships with STEM educators that establish a well-defined rationale for collaboration across linguistics and STEM, yielding basic and applied research benefits.

1. Introduction

In 2010, the Linguistic Society of America co-endorsed a letter to the President’s Council of Advisors on Science and Technology that called on the U.S. to ‘make clear the need for a broad and robust STEM education curriculum that includes all sciences’, including linguistics (Linguistic Society of America 2010: 5). As a scientific discipline that also has roots in the humanities and social sciences, linguistics is uniquely positioned to align with science, technology, engineering, and math (STEM) fields (National Science Foundation 2008). These interdisciplinary connections also provide a compelling rationale for linguists to engage with STEM education and educators. Language is systematic in nature, and the scientific study of language hones inquiry skills that are valued and developed in other scientific contexts (Honda 1994), and students ‘can become engaged in many areas of science through educational experiences in the behavioral and social sciences’ (Linguistic Society of America 2010: 5). Linguistic material is well suited to provide a bridge for teaching and researching when and how cultural, social, biological, and behavioral issues and phenomena related to communication can be explored through scientific inquiry and empirical analysis.

In the context of STEM education in the U.S., ideologies about language and linguistic diversity and approaches to language variation have additional, significant import in the face of data that indicate minority youth often face difficulty in school, particularly in STEM (Tap Coalition 2008). A large proportion of the increasingly diverse U.S. student population includes not only students who are non-native English speakers/emergent bilinguals but also students who speak non-standardized varieties of English (National Center for Education Statistics 2008). Language is a key cultural and social factor that interacts with the norms,
attitudes, and ideologies of educators and students within and outside STEM classrooms and therefore directly affects access to STEM education.

It is critical for linguists and STEM educators to engage in partnerships to address educational opportunity and equality for culturally and linguistically diverse students. Linguists focusing on educational issues have conducted many studies of language attitudes and ideologies, primarily with language arts or other humanities-based educators and students. Most linguistic research does not provide a specialized understanding of the relationship between language variation and STEM teaching and learning and does not yet adequately explore the nuances of STEM educators’ approaches to language diversity in their classrooms and the language ideologies of STEM educators and students. To address these research gaps in ways that promote collaboration and implementation, we provide a conceptual framework for linguists to build and strengthen research partnerships with STEM educators to promote student achievement. We survey how linguists have engaged with educators and teachers, adding to humanities- and social science-based partnerships those with STEM. We review key issues and themes surrounding language and STEM education, focusing on specific and significant structural, sociocultural, and ideological barriers to STEM achievement for culturally and linguistically diverse students. Finally, we describe and advocate for forging partnerships that establish a clear rationale for collaboration between linguists and STEM educators, both for academic and applied benefits.

2. Linguistics and K-12 Engagement: From Humanities and Social Sciences to STEM

Linguists in the U.S. have long been involved in projects that aim to use linguistic theory, methods, and evidence to address the so-called ‘achievement gaps’ in K-12 education, especially for students from groups that have historically been denied access to education, such as African Americans (Alim and Baugh 2007; Ball 1994; Labov 1969; Rickford and Rickford 2007; Wolfram 1969). For students who come to school speaking a non-standardized variety of English, there may be culturally-influenced linguistic ‘mismatches’ between their own communication styles and the expectations that educators have of them (Labov 1972; Piestrup 1973). Linguists have worked to disassociate the notion of linguistic mismatch from that of linguistic deficit (Washington 1996). Such linguistic mismatches are theorized to be a primary mechanism contributing to longstanding opportunity gaps in education (Labov 2008). Rather than ‘achievement gaps’, we use the term ‘opportunity gaps’, situated within a framework of structural social and educational inequality, to focus attention on the persistent society-wide hurdles that hinder the opportunities for academic success for students from historically excluded cultural groups (DeShano da Silva, Huguley, Kakli, and Rao, 2007).

Non-standardized varieties of English, including the cultural and ethnic variety generally referred to as African American English, are often structurally different from the local varieties of standardized English used by teachers and that students are expected to use at school (Charity Hudley and Mallinson 2011). These culturally-rooted linguistic mismatches are theorized to occur particularly in large urban centers of the U.S. and to contribute greatly to persistent education-based social problems (Labov 2008). For example, in a study of 217 young, urban, low socioeconomic status African American students, Charity, Scarborough, and Griffin (2004) found that the ability to shift from African American English (AAE) toward Standard American English (SAE) forms in academic contexts occurred for some but not all AAE-speaking students. They further found that greater facility with style shifting had a significant positive relationship with these students’ reading achievement. In addition, the children who used more features of SAE were more likely to show early reading achievement. One explanation provided to explain this robust relationship is educators’ bias in favor of more standard-speaking children, which positively affects those students’ educational outcomes.
To address linguistic roots of opportunity gaps and inequality for culturally and linguistically diverse students, linguists have generally directed their efforts toward two factors: 1) improving the reading skills of students who speak non-standardized varieties of English and 2) addressing teacher bias against such varieties. Many linguistic materials to help educators improve students’ ability to decode standardized English forms have been designed for K–12 educators in language arts and for reading/language specialists (e.g., Wolfram and Adger 1993; Labov, Dickson, Charity Hudley, and Thorsnes, 2010). Other materials have focused on contrastive analysis techniques to be primarily used in language arts classrooms (Brown 2009; Wheeler and Swords 2006, 2010) or on applying linguistic insights to the study of common diagnostic measures, which often overpenalize the use of non-standardized features (Charity Hudley and Mallinson 2011; Garrett 2009; Taylor 1973).

Numerous studies also address teacher language attitudes toward non-standardized varieties of English. Most educators in the U.S. do not have detailed or accurate information about the varieties of English that their students speak and are largely not trained to deal with linguistic diversity in the classroom (Charity Hudley and Mallinson 2011; Delpit 2002; Fogel and Ehri 2006; Wolfram, Adger, and Christian, 2007). Educators may hold damaging stereotypes about non-standardized varieties of English, especially AAE (Godley, Sweetland, Wheeler, Minnici, and Carpenter, 2006; Lazar 2007; Terry 2008). They may perceive students who speak non-standardized varieties of English as less capable, setting lower expectations for their academic success and limiting opportunities (Goodman and Buck 1973; Lippi-Green 1998).

Some linguists have worked to counteract teacher linguistic bias and improve student reading skills by developing materials that integrate linguistic and cultural instruction. Notable examples of such materials include Rickford and Rickford (2000), Labov and Baker (2005), Craig and Washington (2006), Reaser and Adger (2007), Wolfram and Reaser (2007), Wolfram, Adger, and Christian (2007), and Charity Hudley and Mallinson 2011. Integrated instruction for K–12 educators has shown that teachers’ language attitudes and pedagogical practices generally improve after having been exposed to discussions of linguistic and cultural diversity and educational equality. Such training also positively affects students’ facility with standardized English and their ideas about language differences (Fogel and Ehri 2000, 2006; Godley et al. 2006; Reaser 2006; Reaser and Adger 2007; Rickford 1998; Sweetland 2006).

Culturally and linguistically diverse students do not leave their language patterns at the door when they enter STEM classrooms. For this reason, in K–12 STEM education – as in the humanities and social sciences – a greater understanding of language diversity and of how symbolic and structural effects intertwine to affect language development is necessary to effectively teach culturally and linguistically diverse students. To transmit this information to STEM educators, in particular, requires that linguists develop our knowledge base about K–12 STEM education and educational access, as we have with humanities- and language arts-related fields. The following section reviews how linguistic and cultural mismatches surface in and affect STEM education in the U.S., followed by needed research and action plans to address gaps in the linguistics/STEM education interface.

3. Linguistic and Cultural Mismatches in STEM Education

Much theoretical and empirical literature in education, linguistics, and related fields has explored how linguistic and cultural mismatches contribute to opportunity gaps for culturally and linguistically diverse students (for an overview, see Villegas 1998). Especially in STEM contexts, these students may face such mismatches, which can be structural, sociocultural, and ideological and which overlap and interact to affect student achievement (Hyde and Mertz 2009).
One primary structural barrier, rooted in linguistic inequality, is the language used in STEM educational settings. Academic language in general can often stymie students who are unfamiliar with how it differs from everyday, conversational language (Cummins 1991). Accordingly, education theorists such as Bunch (2013) have noted the importance of ‘pedagogical language knowledge’, calling for educators to be prepared to teach the language of the content area they teach, not just the content itself. Beyond the difficulty that academic language can pose for students are additional, STEM-specific linguistic challenges. First, as STEM classrooms diversify, the way language is used must facilitate student learning. However, research has found that the privileged language in STEM settings is often a masculinized, European, middle-class mode of discourse that privileges scientific evidence over discussions of culture and often does not often examine language as a factor in scientific study (Burke and Mattis 2007; Busch-Vishniac and Jarosz 2007; Foer, Walden, and Trytten, 2007).

Additionally, the language of STEM fields (e.g., the language of science, the language of math) can be a barrier for culturally and linguistically diverse students (Janzen 2008). Lexicogrammars used in STEM texts are often difficult for all students but may be particularly less accessible to students from underrepresented groups, who may be less familiar with academic language (Morgan 2006; Schleppegrell 2004; Wellington and Osborne 2001). It is obvious that STEM fields have their own jargon and terminology, but more subtly, the structure of STEM texts and how language is used in STEM classrooms can also pose challenges. In early grades, students may not be aware, without being taught, that terms such as ‘solve for’, ‘find’, and ‘evaluate’ may be synonyms. Specialized verbs, such as ‘calculate’ and ‘subtract’ instead of common phrasal verbs, such as ‘work out’ or ‘take away’, are common, despite the fact that STEM educators may not explicitly teach students about contrasts in vocabulary words (Schleppegrell 2004; Wellington and Osborne 2001). Grammatical issues include the use of the passive voice, as in phrases like ‘chemical changes are added and subtracted’; such structures, which obscure the human agency involved in procedures, contribute to misunderstandings by student readers (Morgan 1998).

Similarly difficult to parse are structures that contain nominalization, as in ‘The first increase is by five’ (Morgan 1998) and that have high lexical density, as in, ‘The model rests on the localized gravitational attraction’...’ (Halliday and Martin 1993; Wellington and Osborne 2001).

Research on how these structural issues in STEM teaching and learning affect students has largely centered on English Language Learners/emergent bilinguals (Lemke 1990; Lindholm–Leary and Borsato 2006; Schleppegrell 2009). These linguistic challenges are also highly relevant to students who are native speakers of English but who speak a variety that is non-standardized (and often stigmatized). These populations can include students who speak cultural and ethnic varieties of English, such as African American English; those who speak regional varieties, such as Appalachian English; and those whose families have experienced generational poverty and who may have less access to the types of School English or academic English that are valued in educational settings (Charity Hudley and Mallinson 2011). Indeed, the “vocabulary, strategies, or conventions of middle class life [...] are often] assumed to be what ‘everyone knows ’ ” (Delpit 2012: 55).

The research literature in education and linguistics remains sparse as to how language and STEM interact for these populations of students – for instance, in how the students use language in science settings, how they engage with STEM registers, and the specific role that language variation may play. In STEM settings, especially in word problems, test questions, and verbal instructions, teaching and learning often depends on students understanding relational terms, such as ‘next to last’, ‘below’, and ‘until’, which refer to spatial, temporal, ordinal, positional, causal, and logical relationships between objects and events. Many relational terms can express the same idea (e.g., beginning, first, start), but all terms may not
be part of every student’s linguistic background. Scarborough, Charity, and Griffin (2003) gave groups of low socioeconomic status kindergartners and first-graders a 32-item Comprehension of Relational Terms (CORT) test and investigated how they interpreted instructions containing relational terms. Students understood most of the terms referring to spatial relationships, but many struggled with other relational terms, including beginning, middle, end, exactly the same, a few of, and most of. By first grade, most students had vastly improved their understanding of relational terms, but for other students, such terms remained incomprehensible, even after a year of schooling.

Another language-related issue concerns the use of existential it and there, which are prevalent in STEM texts such as word problems, as in, ‘There are six apples in the bag.’ Yet, the use of existentials can vary by language variety (e.g., ‘It’s six apples in the bag’ in AAE) (Charity Hudley and Mallinson 2011). In a similar vein, Terry, Hendrick, Evangelou, and Smith (2010) studied how language variation may increase the cognitive load on students who speak AAE and thereby affect their understanding of and the speed with which they work through STEM texts. They examined the relationship between the linguistic complexity of math word problems and success in carrying out the computation for 75 African American second graders. They found a statistically significant effect for possessive –s (e.g., ‘my mama house’ vs. ‘my mama’s house’) and 3rd singular –s (‘He eat a lot’ vs. ‘He eats a lot’) on the students’ math performance: for students who were highly affected by linguistic differences, about 15% of them would have answered 94 more questions correctly (about 9% of the total) if these linguistic features had been removed. Terry et al. suggest that some AAE-speaking students face an added cognitive load on their working memory when they read and process math word problems, due to language variation – and time spent ‘translating’ while taking standardized tests is time lost.

More research is needed to fully understand how language variation affects teaching and learning in STEM educational settings and, as a result, the academic success of culturally and linguistically diverse students. As Morgan (2006: 338) asks, what happens when students who come from different cultural backgrounds from STEM teachers produce oral and written texts ‘at odds with those the teachers might have produced themselves?’ Just as important as the language of STEM is the question of how STEM teachers respond to language variation, as well as their notions of the standard and how they adhere to classroom language standards. For instance, educators operating with folk linguistic understandings of language variation (Niedzielski and Preston 2003) may evaluate students who speak non-standardized varieties of English – and the academic work they produce – less positively, in informal and formal assessment situations.

Students who experience cultural and linguistic mismatches may also face situations of solo status, stereotype threat, and microaggressions during their educational careers, each of which can cause writing and speaking anxiety and affect how students behave and talk in class. Solo status refers to situations in which students find themselves to be one of very few or the sole representative of their racial/ethnic or gender group (Sekaquaptewa and Thompson 2002) – the only Black student, for instance, or one of just a few female students in a given class. Solo status is particularly relevant to STEM classrooms, where the underrepresentation of women and minorities is prevalent and persistent. Solo status can cause students to feel that their ability to perform in the class is being questioned by others and perhaps that they do not belong, or they may feel extreme pressure to perform better so as not to confirm negative stereotypes about themselves in others’ minds.

Stereotype threat (Steele and Aronson 1995) refers to the fact that negative social stereotypes and lower expectations can severely affect test takers from stigmatized groups on a psychological level, particularly minority students. Steele and Aronson (1995) found that African
American students at Stanford University were more likely than White peers to experience test anxiety and underestimate their own performance on tests. For tests with a verbal component, conventional testing situations have been shown to cause African American students to become hesitant and taciturn (Labov 1972) or to perform less well than their ability level would predict (Steele and Aronson 1995). In the classroom, students from stigmatized groups may avoid speaking up in class out of the fear that if they make a mistake, it will confirm negative stereotypes about them in other students’ or educators’ minds (Charity Hudley and Mallinson 2014). For example, residents of Appalachia have been known to not discuss challenges related to school or educational attainment with outsiders, out of fear that ‘doing so would only further bolster pervasive stereotypes that cast the region as illiterate’ (Locklear 2011: 3).

Finally, culturally and linguistically diverse students often encounter microaggressions, a term that refers to everyday biases and indignities faced by members of marginalized groups (Sue 2010). Racial, gender, and sexual-orientation microaggressions are commonly discussed in academic contexts, but the concept also applies to language, and linguistic microaggressions can interact with microaggressions based on ethnicity, gender, sexual orientation, age, region of origin, and more (Charity Hudley and Mallinson 2014): for example, consider such statements as, ‘I’ve never heard an intelligent person talk the way you do’, ‘I didn’t expect for you to sound so eloquent’, and even more directly negative statements such as, ‘We speak English in this classroom.’ According to Sue (2010), microaggressions are commonplace, constant, and continuing experiences for members of marginalized groups. Even though they may occur in brief exchanges, microaggressions can result in serious psychological and social consequences – such as feelings of powerlessness, a sense of inferiority, and pressure to assimilate – that can have a damaging cumulative effect. In STEM classrooms, as in all classrooms, linguistic, sociocultural, and educational issues are intertwined and are directly tied to the underrepresentation of minority students and their academic achievement.

Although linguistic and cultural difference can cause challenges, difference can also provide opportunities for bridging pedagogical gaps, as some research indicates that educators who are trained to value and build upon students’ linguistic diversity may be particularly successful in teaching culturally and linguistically diverse student populations in STEM. Brown (2006) conducted an ethnographic study of African American students in Detroit, Michigan, and found that the teacher’s method of explaining science ideas by using AAE as well as academic language (in a science register) helped scaffold students’ discourse and develop their science literacy. Research by STEM education scholars Moore (2007, 2008) and Brown and Spang (2008) has investigated the role of language as a gatekeeping mechanism in science education and noted the importance of STEM educators who understand linguistic diversity. Dunstan (2013) found that Appalachian students who attended a large research university in the Southern U.S. often felt more comfortable in certain STEM courses – for example, animal science, agriculture, civil engineering, and mechanical engineering – because they tended to attract students from rural backgrounds, and professors in these areas more often shared similar backgrounds to the students. As Dunstan (2013: 290–91) notes,

there may be differences in the tolerance for linguistic diversity in different departments on campus because of the student population drawn to those disciplines… Subsequently, the areas in which [students] feel greater sense of belonging and acceptance may be influenced by language.

Other models of successful endeavors come from current work on culturally responsive STEM education. Moses and Moses (2012) discuss the Algebra Project, which particularly targets African American boys in grades K–12 to help them excel in mathematics. Terry and McGee (2012) reveal how high-achieving, mathematically-successful Black male
students rely on support networks to succeed, and Maton, Hrabowski, and Schmitt (2000) analyze best practices for promoting the success of high-achieving African American students in the sciences via scholar programs. Hanson (2009) examines African American girls’ science ideologies and how educators’ beliefs about African American student achievement affected the girls’ STEM experiences. Collins, Deer, and Gilbert (2012) explore the use of hip-hop in chemistry classrooms to engage underrepresented minority high school students. In-depth descriptions of other interdisciplinary partnerships between STEM educators and educators from humanities and the arts, in K-12 and in higher education, are given by Brozo and Mayville (2012), Busch-Vishniac and Jarosz (2007), Pomeroy (2012), and Sunstein, Liu, Hunsicker, and Baker (2012). Endeavors that address cultural differences while avoiding a deficit approach would benefit from adding a linguistic lens to the analysis, to illuminate language as a key cultural factor that interacts with norms, attitudes, and ideologies, within and outside STEM classrooms. Adding a linguistic lens would enhance existing materials and provide richer models of culturally and linguistically responsive teaching. To do so necessitates that linguists explore not only cultural mismatches and miscommunications but also successful cross-cultural communication and linguistic and cultural strategies that support diverse STEM educators and students.

4. Needed Research and Action Plans

With respect to STEM education in particular, the need for more research to explore the role of language in how educators teach culturally and linguistically diverse student populations remains acute and is particularly relevant to the question of student persistence and achievement (Valla and Williams 2012). Prior research has suggested that STEM educators may be unprepared to address issues of language diversity, as they may not realize these issues are just as critical in their classes as they are in the language arts (Lemke 1990, Lindholm-Leary and Borsato 2006; Schleppegrell 2009: 17–18). But a more systematic study is needed to determine whether STEM educators have received specific training in language, literacy, and culture, and if so, how much and how relevant they find such training. With this information, linguists will be better equipped to understand the knowledge base of STEM educators, especially with respect to subjective judgments regarding linguistic differences, social and linguistic norms, pedagogical practices, and methods of student assessment within locally situated school contexts. Linguists will thereby also be better equipped to assess how models about how language variation and language ideologies—which to date have largely been conducted within the context of humanities-based curricula and pedagogy—hold (or not) when applied to STEM education.

To achieve these research and applied goals requires sustained partnerships between linguists and STEM educators. By ‘partnerships’, we refer specifically to collaborations between linguists and educators working together to integrate knowledge of language, literacy, and culture into pedagogy to promote educational equality (Mallinson, Charity Hudley, Strickling and Figa 2011). Building on our previous and ongoing work with educators (Mallinson and Charity Hudley 2011) and as part of a 3-year research study funded by the National Science Foundation (Mallinson and Charity Hudley 2011–2014), we have been working with K-12 STEM educators primarily in Maryland and Virginia to explore predominant norms, attitudes, and beliefs about language standards and language variation in STEM education and to determine how linguistically and educationally informed strategies can positively impact the teaching and assessment of culturally and linguistically diverse students. Another model, funded by the National Science Foundation, is the joint initiative recently established between Michel DeGraff at MIT and the government of Haiti to promote the
use of Kreyòl (not only French) in STEM education, to foster the academic success of Kreyòl-speaking students. The initiative supports the development of online, open-access educational resources translated into Kreyòl, created via collaborations with professors and educators from educational institutions and organizations in Haiti (DeGraff 2013). While the implementation of partnerships with educators, students, schools, and communities can be challenging, linguists have begun to pay more attention to the methodological, ethical, and practical issues of collecting data and establishing research- and outreach-based community and educational partnerships (Charity Hudley 2013, Mallinson 2013, Starks 2013).

Other partnerships, as Battistella (2010: 22–3) notes, can connect organizations and institutions:

Linguists should develop some strategies like those of the National Center for Science Education or the Arts Partnership for promoting the role of linguistics into the schools and for helping teachers respond to local issues related to grammar and dialect.

We concur in the clear need for linguists to help provide STEM educators with the training they need in language, culture, and education, so that they can apply their insights to their pedagogy. This call to action emphasizes the need to understand what STEM educators know about language – and if they need more information, providing it – before assessing what is or is not being taught. In our own partnerships, we have found that many STEM educators are already attuned to language diversity and language-based challenges in teaching, but they often need more tailored, STEM–relevant information to fully understand the issues. As one educator from Maryland put it, ‘I’m a computer teacher. I see every class as an English class; it’s just the content that differs.’ Many other STEM educators who we have worked with indicate that students, especially those from underrepresented groups, often have difficulty ‘reading for meaning’. But although these educators view language as a necessary component of STEM education, they explain that they have had little specific training in this area and that this gap hinders their ability to serve culturally and linguistically diverse students, who are most likely to face the educational inequality that persists in STEM.

Local educational context is a significant factor when establishing in-school partnerships. It is important for future research to explore linguistic and sociocultural aspects of K–12 STEM teaching and assessment in a diverse range of institutions (private and independent K–12 schools, community colleges, 4-year colleges and universities), in different regions of the U.S., and in light of system-, state-, and national-level standards and policies. Grade level and content area also matter, and linguists and educators can determine together which materials, methods, and strategies best serve their student populations. For example, linguists can work with elementary teachers to examine how relational terms or specialized verbs are used in word problems in ways that might be unfamiliar to students, or with secondary teachers to investigate how science texts incorporate high lexical density, nominalization, and the passive voice. Educators can also develop their own classroom content and techniques that draw upon linguistic information and their own pedagogical expertise.

5. Conclusion

Through long-term, collaborative partnerships with STEM educators, linguists and educators will be able to extend models that position language as a key explanatory mechanism in educational inequality in the U.S. and further develop materials to address opportunity gaps in STEM. Partnerships between linguists and STEM educators would strengthen what is known about the intersection of language, culture, and STEM education. Language variation and language ideologies directly relate to STEM educators’ pedagogy and practice and, as a
result, have direct impact on culturally and linguistically diverse students’ educational experiences in STEM.

Stronger connections between linguistics and STEM will also benefit higher education, and it can help sustain and diversify linguistics as a discipline. Linguistics can be marketed as a viable option for a double major, as students who combine interests in linguistics and STEM are well equipped to serve culturally and linguistic diverse communities. According to Battistella (2010: 23),

“We need to show how linguistics trains students in the use, history and psychology of language and communication and how it prepares students for careers ranging from writing and editing to medicine, law, and technology and public policy.

As linguistics is integrated further into STEM education and as linguists advocate nationally for STEM education, a broader base of students will be involved in the study of language, culture, and science, helping to ensure that future generations of linguists will be prepared to add to what is known about the nature of language use in diverse linguistic, cultural, and social settings.

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Partnering Through Science


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