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Affordances of engineering with English learners

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Abstract

In this position paper, we draw from previous research and theoretical developments in the field to propose a set of affordances of engineering with English learners (ELs). Students learning both the language of instruction (e.g., English) and academic subject matter (e.g., engineering, mathematics, science) face the challenge of making sense of linguistically complex terminology of disciplinary knowledge. We posit that engineering provides a unique set of benefits for such learners due to a number of factors associated with the discipline of engineering, including the materiality of the knowledge, the potential for multimodal communication, and the contextualization of knowledge in specific task-oriented activities. We also recognize that engineering benefits from participation by diverse learners including ELs as solutions are strengthened by a multitude of ideas and perspectives. Although this paper focuses on ELs, we recognize that such affordances are also valuable for *all* students, including native English speakers, and that they may be particularly important for students who may benefit from additional linguistic supports for developing academic literacies. We identify the affordances, anchoring them in elementary classroom experiences and teacher testimonials, and propose a research agenda for future study.

KEYWORDS

disciplinary knowledge, discourse, emergent multilingual, engineering, English learners, identity

1 | INTRODUCTION

English learners (ELs) are one of the most rapidly growing populations in elementary schools (National Clearinghouse for English Language Acquisition, 2011; Sugarman & Geary, 2018). Over 16% of children entering kindergarten are ELs and this number is growing (National Center for Educational Statistics, 2018). These students bring a wealth of perspectives, resources, and ideas to the classroom including knowledge derived from experience in their communities, local know-how, uses of materials, and other funds of knowledge (González et al., 2005; Moll, 2019). They need the opportunity to participate in classroom lessons, including those in engineering and science, to develop an interest in and knowledge of these fields. A recent report by the National Academies of Science, Engineering, and Mathematics, *English Learners in STEM Subjects* (2018), calls for approaches to teaching science, technology, engineering, and mathematics (STEM) that invite students to develop language proficiency as they engage in STEM practices. The report examined the existing research related to STEM and ELs (see the next section for a discussion of terminology) and called for more research in a variety of domains. The lack of research regarding the education of ELs is particularly apparent in engineering education; yet, as we argue in subsequent sections, the field of engineering has much to offer. The inclusion of engineering in the *Next Generation Science Standards* (NGSS Lead States, 2013) has raised awareness of the importance of introducing children to this subject. The standards recommend that these efforts begin in elementary school and involve all students. This needs to be done in ways that build on the strengths of the students and provide supports for learning engineering and science.

In this position paper, we argue that engineering education can provide beneficial learning opportunities for ELs. We offer preliminary evidence from the current research base to identify features of disciplinary knowledge and practices of engineering that afford learning opportunities for ELs. Engineering entails a problem-solving orientation and usually depends on active engagement with materials and people to address design challenges. Features such as the materiality of design knowledge, multimodal communication across audiences, and the contextualization of knowledge in specific task-oriented activities situate students in contexts consistent with affordances for learning derived from sociocultural theory regarding language development. Furthermore, the relationship is bidirectional as engineering education, and engineering as a field, benefit from participation by diverse learners, including ELs; the array of ideas, perspectives, and approaches they contribute strengthen design solutions. To date, this potential has not been fully recognized by either schooling or educational research. We address this potential educational opportunity by proposing six posited affordances of engineering with ELs that can guide a research agenda. These affordances are anchored in classroom experiences and teacher testimonials and are consistent with sociocultural research perspectives regarding ELs.

The origins of this essay emerged from intriguing observations by classroom teachers about the engagement and experiences of ELs during engineering experiences. A number of teachers remarked that students who had not fully participated in classroom life became engaged in the academic work of engineering in new ways. Teachers noted that during engineering activities students were able to draw from their experiences, use their knowledge base, and find ways to communicate and engage with fellow students around design issues. This led our research team to conversations, focus group discussions, and a pilot study that suggested that engineering may provide valuable affordances for ELs (Cunningham et al., 2019). To interrogate these initial observations, we reviewed both research regarding ELs in science and engineering, and a body of literature about disciplinary knowledge and practices in engineering across professional and educational settings, including empirical research from the field of science and technology studies. Although these bodies of research informed our research questions, they were insufficient to examine the nature of the learning experiences observed by the elementary teachers. Furthermore, the fledging literature about engineering and ELs has not fully considered how to leverage assets brought by students and the affordances of engineering in school settings. Therefore, based on reports from classroom teachers and current research across the disciplines, we hypothesize six affordances for engineering with ELs as part of an emerging research agenda.

Before turning to the learning theory informing our work, the extant literature on learning content and language concurrently, and the posited affordances forming our proposed research agenda, we acknowledge that naming conventions for students learning languages are inadequate. As such, these conventions potentially limit the characterization of the cultural and linguistic complexity in populations and even individuals. We situate the study within our personal language histories, noting that our own linguistic diversity is not captured by the many ways learners of academic content and language are referenced in the research literature.

2 | LINGUISTIC DIVERSITY, NAMING CONVENTIONS, SITUATING OURSELVES

Students learning academic content in a new language for them in the United States (English) have been referred to as students learning English as a Second Language (ESL), Second Language Learners (L2), English Language Learners (ELLs), English Learners (ELs), Dual Language Learners (DLLs), Emergent Bilinguals (EB), and Emergent Multilinguals (EM). Students in our nation's schools bring a wealth of language experiences and histories. Thus, each of these terse labels falls short in describing the nature of the language experiences of the students in K-12 classrooms. Our own language histories themselves cannot be easily labeled—we describe our relationship with learning multiple languages and disciplinary knowledge to situate ourselves in this study and articulate our backgrounds and commitments. Through this exposition, we evince the inadequacy of labels even for our own limited experiences. This inadequacy is exacerbated in schools that encompass students with an extensive range of cultural and linguistic backgrounds, resources, and experiences.

A native speaker of English, Christine was interested in other languages from a young age. She studied French, Latin, and Spanish in junior and high school and chose to graduate from high school early so she could experience a different culture and language by studying abroad. For a year, she lived with a Spanish family, attended a local high school, and spoke only Spanish. Through immersion, she experienced the frustrations and challenges of learning disciplinary knowledge in a second language. In social situations outside the classroom, Christine was functionally bilingual but also identified as a Spanish Learner. In contrast, in academic settings where discipline-specific terminology was necessary, her linguistic abilities in Spanish often impeded her understanding of the disciplinary knowledge. As a researcher and curriculum developer, she has been committed to engaging students, particularly those who are underserved or underrepresented in STEM fields, in disciplinary knowledge through equitable, relevant, and rigorous curricula. Her work in engineering education has demonstrated the importance of situating engineering designs in cultural contexts.

Greg had difficulty learning to read and write in English, his native tongue. He struggled in school, particularly in language arts. Because of this, he gravitated toward mathematics and science, earning an undergraduate degree in physics. After graduation, he served 4 years in the Peace Corps in Togo, West Africa. There he became functionally bilingual as he taught high school physics and chemistry in French—the *lingua franca* of the country. Greg's multilingual Togolese students all spoke one or, more commonly, multiple indigenous African languages before entering school. In school, they also learned French and were taught all content in French. The language-learner labels above (as French, not English, learners) fail to capture the complexity of the language phenomena of the classrooms where Greg taught. As a teacher, he was a French Second Language Learner and (an emergent) bilingual. His students do not fit into any category. Depending on the language they were speaking and context or discipline they were in, their status changed. Interestingly, they were learning physics in their native country, but in a foreign tongue. This posed additional challenges for both the students and the teacher. Throughout his career as a teacher and researcher, Greg has been committed to educational equity through demystifying knowledge and practices for all students.

Natacha was born in Brooklyn to Haitian immigrants. Her home language was Haitian Creole. However, when she entered school, she was misidentified as an English speaker due to her birth country and was instead mistakenly flagged as requiring special education services. Mostly silent in elementary school, she did not receive formal ESL services until fifth grade. Although she spoke Haitian Creole with her parents, as she and her siblings learned English, this became the language they chose to communicate among themselves. By the time Natacha entered college, she was mostly bilingual, but never learned to write in Haitian Creole. In college, she studied Spanish, which felt familiar in comparison to Haitian Creole due to the overlap of cognates in both languages and became proficient in this language. Driven by her own educational experiences, Natacha pursued roles in education that supported ELs. As a middle school ELL Administrator and ELL teacher in Boston, MA, Natacha supported a multilingual student cohort. The multiplicity of languages that were present made it particularly challenging to develop resources and English classes that were appropriate for all students. She has continued to develop curricular resources for students learning English as another language, recently focusing on elementary and middle school engineering. In Natacha's three languages, her use, communication, and modes of mastery have varied. Static, unidimensional labels cannot adequately describe her language histories.

Across our three examples, we note that labels often fail to capture the range and uses of language in society. For this paper, we have chosen to employ the term ELs. We are focused here on educational settings, particularly schools, and ELs are the subset of multilingual students that schools identify as in need of linguistic supports to fully access academic content in English. We choose this terminology, which is employed by the federal government, districts, and teachers, because identification as an EL by a school district results in decisions about students' educational experiences. However, we acknowledge ELs' linguistic resources as assets and recognize that many of these students are EMs who are developing proficiency in multiple languages simultaneously. It is important that the research community recognize the assets brought to the educational settings, regardless of label, which is what we attempt to do in this essay. While there are many goals for elementary education, concurrent learning of disciplinary knowledge and language poses important opportunities. We understand that the EL label, or any other label, has limitations and we look forward to dialogue about ways to further understand the nuances and complexities of students' language competencies.

Our motivation to propose affordances of engineering with ELs is derived from our commitment to educational equity and our experiences with engineering and classroom teachers. These teachers reported changes in students' interest and engagement, uses of language, and small group participation and contributions that were particularly evident for students learning English (Cunningham et al., 2019). These experiences are consistent with findings of other researchers who noted that engineering has the potential to disrupt classroom hierarchies to expand students' conceptions of who is smart during engineering (Hegedus et al., 2014), and that engineering activities that allow students to express their knowledge in multiple ways that help educators recognize a more diverse group of children as gifted and talented (Robinson et al., 2018). Before turning to the proposed affordances, we situate our work theoretically and review extant research informing the overall perspective.

3 | SOCIOCULTURAL LEARNING OF DISCIPLINARY KNOWLEDGE AND PRACTICES

Sociocultural learning theory informs how we understand students to be situated in cultural, linguistic, social, and institutional contexts. From this point of view, students develop proficiency with disciplinary knowledge and practices through meaningful engagement and authentic discourse (Engle & Conant, 2002; Kelly, 2014). For illustrative purposes, we provide examples from engineering education to ground sociocultural theory in everyday practices of teachers. Properly structured, such engagement provides opportunities for learning the science and engineering, for developing proficiency in social and academic discourse, and for fostering identity development within an epistemic community. In engineering, consideration of discourse processes is particularly important given the need to interact with clients, work on teams, and use multiple semiotic fields to solve complex problems (Cunningham & Kelly, 2017; Kelly & Cunningham, 2019; Wendell et al., 2017). Discourse is defined as language-in-use that includes verbal exchanges, gesture, proxemics, written texts, sign and symbols, and other semiotic resources (Bloome et al., 2005; Kelly, 2014). Thus, authentic academic discourse may include a number of modes of communication including the physical embodiment of a designed device, uses of figures and diagrams, data tables, written language in words and symbols, and verbal exchanges. Nevertheless, across modes discourse entails more than ideational communication as discourse shapes, and is shaped by, sociocultural practices, power, and identity and encompasses the many epistemological, ideological, and social dimensions of language use (Fairclough, 1995; Rogers, 2004).

Engineering design challenges situate students in rich semiotic fields where the materiality of the designed devices and embedded knowledge are interpreted through meaning-making discussions. In this way, discourse serves multiple functions in social situations beyond just communicating information. Social order, relationships, and identity are constructed in and through discourse (Cazden, 2001; Fairclough, 1995; Gee & Green, 1998). As groups (engineering teams, classroom communities) affiliate over time, they establish roles and relationships, norms and expectations, and rights and obligations that come to constitute being a member (Kelly & Green, 2019). Through such social and discourse processes, members of a group create particular ways of talking, thinking, acting, and being. Over time, as these concerted activities become patterned, they establish cultural practices of members of a group (Kelly & Green, 2019; Kelly et al., 2017).

This sociocultural view of learning emphasizes the importance of engaging in the social practices of a discourse community (Gutiérrez et al., 2011), such as those of various engineering fields or classroom communities. In this way, learning occurs in social settings with the artifacts and cultural tools created by more-knowing others (Vygotsky, 1978). Through engagement in engineering design and analysis, students come to internalize the ways of talking, knowing, and being that constitute engineering (Kelly & Licona, 2018). The ongoing, concerted activities of engineering in educational settings provide numerous opportunities to learn the knowledge and practices of engineering and problem solving including addressing client needs, balancing criteria and constraints, optimizing solutions, using evidence to make decisions, and persisting and learning from failure (Cunningham & Kelly, 2017; Wendell et al., 2019). These opportunities provide reasons for students to engage in authentic discourse around purposeful activity (Engle & Conant, 2002; Moje, 2015).

Professional engineering and engineering education represent related but distinct discourse communities with overlapping epistemic practices. Although engineering education makes reference to epistemic practices of professional engineering across contexts, the social activity of education has different aims and purposes. In engineering fields, a given technology or process is created by highly educated experts with deep and unique knowledge of specific domains (Johnson, 2009). In education, the purpose is to expand the repertoire of the discourses of students to provide opportunities for them to engage with their world in new ways, both through continuing education and applying problem solving to sociotechnical contexts in everyday life (McGowan & Bell, 2020). A second clear distinction is the level of the training and knowledge that participants in the discourse community bring to a given engineering project. One role of education is to develop facility with new knowledge and practices that help students develop capacity for engineering design and analysis. A third distinction is the nature of the activity. The epistemic culture of professional engineering is oriented to solving problems for a given client who articulates criteria and constraints (Brophy et al., 2008). Engineering activity in education strives to produce a local epistemic culture that engages students in practices oriented to learning how to engage with engineering design and analysis.

While engineering lessons can be designed to promote discourse among students, draw on student knowledge, and foster the use of multiple modes of communication, such disciplinary discourses pose challenges for all students given new technical vocabulary, interlocking definitions, obscure symbols and notational systems, and nominalization (Ernst-Slavit & Pratt, 2017; Halliday & Martin, 1993; Larsson, 2018). Furthermore, by failing to recognize, acknowledge, and take up students' own ways of knowing, speaking, and being, such disciplinary discourses are potentially alienating, leading to cultural costs for students (Brown, 2019). Such disciplinary discourses similarly challenge students to learn specific norms for supporting claims with evidence and communicate their solution to a larger audience (Kelly, 2014; Moje, 2015). These linguistic features may pose additional hurdles for students learning both disciplinary knowledge (engineering) and the language of instruction. To address the potential limitations of disciplinary discourses, educational opportunities need to create contexts that invite and motivate students to draw from their assets and engage with knowledge(s) in new ways.

4 | ASSET-BASED APPROACHES FOR ENGINEERING EDUCATION WITH ELS

Next Generation Science Standards advocate for more active uses of language to advance learning in science and engineering and pose new challenges and opportunities for ELs. As engineering enters classrooms, careful attention should also be paid to the design of curricular materials, instructional strategies employed, and learning environments that are created to ensure opportunity and equity for ELs (Cunningham et al., 2020). Such resources must be rooted in an asset-based approach to EL education that draws upon the linguistic and cultural strengths of ELs by amplifying, not simplifying instruction (García et al., 2017; Lucas & Villegas, 2013; Rosebery & Warren, 2008; Villegas & Lucas, 2002; Wilson-Lopez et al., 2016; Zwiers et al., 2017). Engineering may offer valuable opportunities for ELs that build on the strengths they bring to the educational settings: knowledge derived from experience in their communities, local know-how, uses of materials, and other funds of knowledge (González et al., 2005).

Lee et al. (2013) identified ways that disciplinary knowledge and practices can be enhanced through particular uses of language that focus on sense-making, include different modalities, and provide access to registers. Such sense-making needs to take into consideration the cultures and lived experiences of the students, the social processes of the educational experiences, and the features of the relevant disciplinary knowledge and practices. There is a paucity of research regarding asset-based approaches for teaching engineering in elementary schools with EL students; we provide a selected review of this extant literature, and in an effort to develop a robust framework, also consider studies of science and mathematics education that can inform engineering education with ELs. We organize this body of research by categories of asset-based approaches for engineering education. In some instances, features of engineering (i.e., characteristics of the disciplinary knowledge and practices) have not yet been investigated by educational research. For these features, we draw from the empirical study of engineering from science and technology studies. A listing of the features that engage ELs in engineering is presented in Table 1.

4.1 | Learning language and disciplinary knowledge concurrently

Specialized academic discourses are social languages that combine ways of speaking, doing, being, and valuing (Gee, 2014). Expanding students' repertoire of academic discourses entails learning more than the syntax, semantics, and pragmatics of the formalized discourses. Rather, to be a member of an epistemic culture, with specialized ways of talking, acting, and being, students need to learn such discourses through meaningful engagement with ideas, texts, and each other. Such engagement needs to include uses of language in purposeful activity around sense-making of ideas, often in children's own discourses. In this way, they actively contribute to the common knowledge and ways of knowing being developed by the local community. For example, Rosebery et al. (2010) showed how students from nondominant communities were able to make meaning around notions of heat transfer through uses of multiple discursive resources. This orientation to learning language through engagement with knowledge is consistent with a review of research of English language learning across academic subjects (de Araujo et al., 2018; Hwang & Duke, 2020; National Academies of Sciences, Engineering, and Medicine [NASEM], 2018; Walqui, 2006; Zwiers et al., 2017) and contrasts with how teachers often view language learning, focusing more on vocabulary development and terminology (Lemmi et al., 2019). Across academic subject matters,

TABLE 1 Features of engineering that engage ELs

Features of engineering that engage ELs	Potential uses for disciplinary learning
Concurrent learning of disciplinary knowledge and language	▪ Includes students in academic work—students not pulled out of class ▪ Develops language through meaningful use ▪ Centers student work on academic knowledge
Open-ended problems	▪ Draws from students' experiences/funds of knowledge ▪ Encourages multiple solutions
Multimodal communication	▪ Integrates language and other semiotic resources ▪ Focuses on communicative goals ▪ Connects with signs and symbols of disciplines
Materiality	▪ Affords alternative communication and participation ▪ Embodies knowledge in the manifestation of the engineering product ▪ Becomes “text” for communication and focuses on meaning, not syntax
Teamwork	▪ Provides setting for cooperative uses of language to solve common problems ▪ Enhances diversity of ideas and approaches that strengthen solutions
Multiple audiences	▪ Provides reasons for explaining differently for different purposes ▪ Provides reasons for different explanations
Contextualized settings for design challenges	▪ Situates science and engineering in socioscientific and sociotechnical issues ▪ Demonstrates relevance of disciplinary (school) knowledge ▪ Connects to students' lives and experiences
Learning from failure	▪ Encourages all students to take risks ▪ Develops persistence and perseverance ▪ Fosters development of first iteration of designs, as initial, not final solutions

learning language and subject matter concurrently is potentially mutually beneficial (Ciechanowski, 2014; Moschkovich, 2002; NASEM, 2017).

4.2 | Engaging in open-ended tasks

Learning disciplinary knowledge and practices can be enhanced through engagement in goal-directed, purposeful activity. In engineering, these activities can be designed around open-ended tasks, offering multiple solutions that invite engagement in productive disciplinary discourse (Cunningham, 2018; Engle & Conant, 2002). Such engineering solutions are often strengthened through diverse and creative approaches based on the students' lived experiences (Tan et al., 2019). Studies in mathematics and science education point to promising directions for engagement by ELs in engineering experiences with similar attributes. For example, in a comprehensive review of ELs in K-12 mathematics education, de Araujo et al. (2018) found that mathematics organized around open-ended tasks focused on meaning-making offered students opportunities to learn academic content through engagement in activity. Similarly, Moschkovich (2018) has identified ways that productive uses of discourse processes support understanding and reasoning in mathematics.

In science education, research has demonstrated that hands-on, open-ended, inquiry-based science lessons allow ELs to engage in the lesson, develop scientific understanding, and learn English (Buxton & Lee, 2014; Estrella et al., 2018; Lee et al., 2016; Zwiep et al., 2011). Research in science education has also highlighted ways that ELs' everyday experiences can serve as resources for learning disciplinary knowledge through engaging in discourse processes (Buxton et al., 2013; Rosebery et al., 2010; Warren & Rosebery, 2008). Such complex discourse practices build on the strengths of ELs and invite them to engage in disciplinary knowledge and practices rather than solely focusing on vocabulary and knowing facts about science (Buxton & Allexsaht-Snider, 2017; Ryoo & Bedell, 2017).

Studies of engineering identify how engineering problems can allow a multiplicity of solutions to open-ended tasks (Johri & Olds, 2011; Jonassen, 2014). The varied engineering approaches and solutions encourage and provide opportunities for youth with different life experiences and ways of knowing to contribute to the common knowledge and discourses of the group or classroom (Wilson-Lopez et al., 2018). Engineering activities that engage students in open-ended problems encourage students to make meaning using language, materials, symbols, graphics, and other visual displays.

4.3 | Using multiple modal communication and discursive resources

Engineering offers the potential to integrate the uses of language and semiotic tools across modes of communication. Tackling open-ended tasks and adhering to the criteria and constraints specified for the problem requires articulation and communication. Thus, the work of engineering itself situates students in a communicative setting where multimodal discourse is valued. Through work on teams, the design and construction of devices foster teamwork and coordination across multiple modes of communication (e.g., physical, verbal, gestural, textual, and symbolic) for meaning-making. Research suggests that providing a number of opportunities to use language through purposeful activity that involve multiple modes can support access by ELs (Lee et al., 2019; McFadden & Roehrig, 2019; Meskill & Oliveira, 2019; Paugh et al., 2018; Wendell et al., 2019). For example, Buxton and Caswell (2020) identified uses of visuals and models to offer meaning-making opportunities for students and found that "engagement in multimodal and intertextual approaches helped students gain access to key ideas" (p. 574). Consistent with multimodal instruction are the use of diagrams, graphics, and models for formative assessment of students' learning (Fine & Furtak, 2020). These examples from science education suggest that such uses of language can engage all learners, and this potential of engineering may similarly be especially productive for ELs.

To date, there has been little research regarding ELs' learning in elementary engineering. One notable exception is a study by Paugh et al. (2018) that identified how a range of discursive resources typically found in engineering provided avenues for ELs to demonstrate their understandings. Demonstrating understanding is needed to situate the students as active participants in their own learning and build common understandings of key ideas in the lessons. The focus on communicative goals of the tasks, situated in social settings, allows for building connections between the discourse practices of students and the standardized signs and symbols of disciplines. In their study, McVee et al. (2017) also found that integrating multiple modes for productive communication provided opportunities for youth to develop disciplinary literacies and identities as engineers in an afterschool engineering program with ELs. Detailed, discourse analysis of the enactment of engineering design in both school (and after school) settings is needed to further examine the benefits and interactions between engineering and ELs.

4.4 | Leveraging materiality and embodied knowledge

Related to multimodal discourses is the materiality of engineering. Engineers communicate using physical objects and models. In K-12 engineering, students often manipulate materials to produce designs and technologies (Cunningham, 2018). For example, as students design an insulated cooler to keep medicine cool, their understandings of insulative properties and arrangements of materials may manifest themselves in the production of their design. In this way, student knowledge is concretized in the designed technology, often before it is articulated across textual forms of communication. Such an alternative form of communication invites participation for ELs, as the emerging iterations of the technology become a "text" for communication and focus on meaning. This example highlights how meaning can be shifted from the syntax of formalized knowledge to the embodiment of student-designed engineering products. Martin and Betser's (2020) study of how youth in maker spaces developed engineering discourses highlighted the relationship between language and materials. Their analysis:

> *shows how the hands-on, open-ended, and youth-driven nature of an activity was linked to the processes of learning. Language and materials were available for low-risk experimentation, and through language and action, mentors and youth made use of the materiality of the activity space as they created linkages between language, object, and process: objects were examined, pointed at, discussed, and assigned roles to play in imagined processes and mechanisms* (p. 209).

The authors recognized the intertwined nature of materials, knowledge, and discourse, recommending that educators design experiences that allow youth to "experiment with both discourse and the material environment" (p. 209).

4.5 | Benefiting from teamwork

Almost all professional engineering requires teamwork and collaboration (Sheppard et al., 2007), suggesting that engineering work is social in nature (Cunningham & Kelly, 2017). Team members share, plan, critique, and negotiate ideas. Furthermore, such groups often include members with a variety of types of expertize (engineers from specialized disciplines, technicians, artists). By assembling teams with diverse perspectives, more innovative and robust engineering solutions can result. Such teamwork involves communicating through a variety of media—oral and written text, diagrams, models, and physical artifacts (Dym et al., 2005). The ability to interpret and communicate across such languages has been identified as one of the most essential skills of an engineer (Anderson et al., 2010).

Interestingly, in educational settings, team or group work has the dual benefit of improving the engineered product and the learning potential of the activity. Similar to professional engineering, creating classroom engineering groups that include a diversity of ideas and approaches strengthens solutions. Additionally, by working together in pairs or groups, students develop communication and language skills as they consider others' perspectives, argue from data and evidence, compromise, and select the most promising ideas. All students, but especially ELs, benefit from interacting and collaborating in teams. Well-designed group work provides opportunities for ELs to interact with their peers, produce language themselves, and use language in a context and for a purpose, features that promote language development (Gibbons, 2015). Working with peers creates authentic, meaningful contexts for language learning and production as members discuss and share ideas, negotiate design possibilities, evaluate results, and communicate results to others in the class or community. Such collaborative work may improve engineering learning and identity development among bilingual students (Mein & Esquinca, 2017).

4.6 | Communicating to multiple audiences

Engineering often entails communicating with a variety of audiences such as other team members, potential clients, and users of a product or technology. Communicating with audiences with different cultural, linguistic, and epistemic backgrounds, requires students to employ various registers tailored to the situation. Both provide an opportunity to learn from engaging in language in different ways and to demonstrate their knowledge across modalities (Lee et al., 2013). Such experiences can facilitate productive student discourse, particularly for ELs (Lyon et al., 2018). The use of varied audiences for eliciting student knowledge was found to be effective in a study by Crawford et al. (1997). These authors examined how bilingual high school students varied their discourse when speaking to visiting language-diverse fifth grade students, as compared to their presentation to the classroom teachers. When the high school students explained their science exhibit to the visiting fifth grade students, they recognized the need to adjust their explanations and occasionally code-switch to Spanish to communicate the science concepts. In this case, the communicative context provided opportunities for bilingual students to draw on their full repertoire of linguistic resources, including spoken, written, symbolic texts, as well as choices of the primary language for communication given the visiting audience groups. Similarly, Buxton and Caswell (2020) identified how variation in audience allowed for choices of register to support the communicative goals of the students. Thus, the variation in audience provides authentic reasons for explaining the disciplinary knowledge inherent to a device or technology differently for different purposes. Recognition of and practice across audiences can develop increased learning of the engineering entailed in the conversations as well as facility with language.

4.7 | Situating design challenges in contextualized settings

Engineering occurs in real-world contexts. Engineering challenges can be set in local or community settings, encouraging students to draw upon their home knowledge and cultures. Design challenges connected to socio-scientific issues may pique students' interest because students learn science and engineering through reasoning that entails analyzing, evaluating, and discussing complex, ill-structured problems that draw from scientific, economic, and ethical reasoning (Sadler, 2009). Situating learning in socioscientific issues has been shown to motivate students and engage them in multiple discourses. For example, Licona (2019) studied ways emergent bilinguals used evidence as they debated the ethical implications of technical solutions for invasive species.

Engineering is inherently connected to such societal issues and draws from multiple reasoning spheres. Linkages to students' lived experiences have been shown to foster a more equitable education. For example, Tan et al. (2019) demonstrated ways that middle school students can define engineering problems related to their community and use iterative design to balance trade-offs between technical and social considerations. Their findings echo those of Licona—through such work the students recognized the potential relevance of science and engineering to their community, cultures, and lives. Such linkages invite students to understand science and engineering in new ways.

4.8 | Learning from failure

Failure exists in many parts of life and traverses academic disciplines, but engineering has a unique relationship with failure (Petroski, 2006). Engineers test designs to failure to understand their limits and to learn more about structures and systems behave (Adams, 1991; Madhavan, 2015). Failure is also an expected part of the development of designs. The reasons, stakes, and purposes can vary. Some designs go through multiple rounds of failure, leading to incremental improvement—WD-40, for example, was the 40th attempt at a formula for the now-famous lubricant. Other times failure can be catastrophic and quite public. Johnson (2019) studied failures during engineering design in elementary classrooms to identify how it can lead to productive discourse and learning. His research demonstrated that the teachers' and students' reactions to initial failure lead to differential opportunities to learn. Similarly, Lottero-Purdue and Parry's (2017) study of teachers' and students' response to failure during elementary engineering lessons found that as teachers gained familiarity and comfort with ways of handling and talking to students about failure, they were able to communicate messages that cast failure as a learning opportunity that leads to better designs. The teachers were also able to support students to do so. Wendell and Kolodner (2014) offer a set of affordances that promote engineering disciplinary practices and idea development in students.

Among these, they note the importance of failure and iterative design for students' testing and refining of nascent conceptions and practices. While not centered on ELs, these studies touch on points endemic to the nature of engineering practices that can support language and content learning.

From a pedagogical point of view, learning from failure encourages all students to take risks and develops persistence and perseverance. Progress after initial failure instills the principle of progressive improvement through thought, work, and trial. This holds for engineering designs as well as language. Students learn that first designs are not likely the final solutions. Through the iterative cycles, the discourse processes mentioned above become salient as teams iterate solutions over time. Furthermore, because most students have not previously encountered engineering instruction, engineering activities provide a learning environment where all students are relatively new to disciplinary knowledge and practices. As such, this can decrease the reliance on exposure in the previous schooling to ideas, skills, and resources to create more equitable learning spaces where multiple knowledges and experience are more relevant.

5 | AFFORDANCES OF ENGINEERING TO SUPPORT LANGUAGE DEVELOPMENT

Based on extant literature, our own studies of elementary engineering education in classrooms with ELs, and reports from teachers in our research samples, we began to pose questions: What are the affordances of engineering with ELs? How can affordances of engineering with ELs be realized? What are the educational opportunities and constraints to fostering access to STEM knowledge through engineering for ELs? As we considered such questions, we articulated, refined, and revised a set of six hypothesized affordances of engineering for language development of ELs. These affordances take into consideration the features of engineering supporting learning (see Table 1) and are summarized in Table 2.

This section explores these affordances in more depth. For each affordance, we provide a description and offer an example of the type of elementary classroom engineering experience that creates such learning opportunities. To examine whether the potential of the theoretical benefits of the affordance was recognized in classrooms, we collected information from teachers of ELs across the United States who had previously taught engineering using design challenges in the classroom. We share testimonials provided during focus group interviews and surveys by teachers of ELs who recognized the benefits for their students (Cunningham et al., 2019).

These teachers were first asked generally to describe their ELs' experiences during engineering activities. Then we asked them to indicate whether or not they observed each specific affordance we had posited and if so, invited to describe how it had manifested in their classrooms.

5.1 | Affordance 1

Engineering supports language acquisition by providing opportunities for ELs to practice and develop their social and academic language skills as they work in collaborative groups to negotiate design decisions that are meaningful to them.

Engineering challenges can connect children to a real-world problem that they want to solve. Students are more likely to use and learn language when they are motivated to communicate with others to accomplish a goal that is meaningful to them (Moje, 2015; Short et al., 2018; Snow, 2017). Hands-on, project-based engineering challenges provide ELs multiple ways to understand the activity and use spoken, written, and symbolic language. Using materials and testing the performance of their design solutions offer experiences and information that supports and encourages verbal communication. In engineering, these deliberations often involve teams of people (Bucciarelli, 1994; Trevelyan, 2010; Vinck, 2003). The teams are strengthened by the many ideas that

TABLE 2 Proposed affordances of engineering with English learners (ELs)

Affordances of engineering with ELs
Engineering supports language acquisition by providing opportunities for ELs to practice and develop their social and academic language skills as they work in collaborative groups to negotiate design decisions that are meaningful to them.
Engineering uses multiple modes to communicate including writing, drawing, and gesturing. Multimodal approaches invite ELs to demonstrate their thinking and participate in small group and classroom deliberations.
Engineering casts failure as an opportunity to learn. This creates an environment that fosters risk-taking among students. This orientation allows ELs to take risks linguistically and engage more actively with their peers.
In engineering, there are often multiple solutions given the criteria and constraints of a particular design challenge. The open-ended nature of engineering problems encourages diverse approaches and solutions. ELs can draw on their experiences as they generate ideas.
Successful engineering design solutions benefit from diverse perspectives. Engineering encourages students, including ELs, to draw from their life experiences and consider their personal backgrounds as assets when imagining and designing solutions.
Features of engineering (multiple solutions, learning from failure, materiality, communication using symbols such as a circuit diagram) foster ELs' success and encourage them to become more active members of the learning community during engineering projects. Consequently, they themselves, their teachers, and their peers have an opportunity to see ELs in a new light.

their members bring and provide many opportunities for rich communication, both spoken and written. ELs can work through their ideas and use language as part of such authentic tasks.

5.1.1 | Classroom example

As a team of three students engineer a package to ship a flowering plant, communication is essential to reaching a group design. To argue that particular design elements contribute to the package's performance, members consider the needs of the plant and the functions of the package. They are motivated to keep the plant alive, healthy, and intact! As students describe to teammates why they believe certain features are necessary, they call upon knowledge they learned previously. They refer to the structures and basic needs of the plant—roots that need to be kept moist, a stem that needs to be supported, leaves that need light, and flowers that cannot be squashed. Their conversations also highlight basic functions of packages such as protecting the contents and communicating what is inside. During discussions about how they should construct their package, the students justify their choices of materials by describing their properties—transparent, absorbent, strong, or inexpensive. As they explain their ideas and thinking, students use new science and engineering vocabulary and concepts. The team needs to consider relevant scientific knowledge, design features and criteria, the aesthetics of the package, and consequences for each of their decisions for other features of the design. These considerations require active communication among team members. Reaching a group consensus requires students to explain their point of view, attend and listen to others, and negotiate about the design their team will build and test.

5.1.2 | Teacher testimonials

The value of engineering for engaging students in academic language was emphasized by teachers who noted how students actively participate during design challenges to articulate their ideas and point of view. The benefits of learning academic language during authentic tasks that used physical materials and allowed children to draw on their previous experiences and demonstrate their knowledge was also noted by teachers.

> *English learners usually understand English better than [they] can communicate it which hinders them when asking and answering questions [in] the core subject areas. I have found that they are more apt to attempt interacting in social activities when working on a[n engineering] design project. When they feel strongly enough about their design decisions, they work harder at making their point of view known. In other subject areas, they usually tend to try to not be noticed.*

> *EL students are immersed in language by doing activities using the engineering design process. They are able to internalize and process language and vocabulary through repetition and experience. Students are able to participate and find success through manipulation of materials, building on their prior experiences and language while building their confidence in engineering, English, and learning.*

> *The EL teacher and I loved doing… [engineering] together because it was a chance for students to use academic language in authentic situations. The part of the lesson where materials are tested was so valuable for all students but was so great for students who may not have used those materials before or didn't have the vocabulary to talk about them. I also love seeing how students could show what they knew through actions or a design working rather than language only. I think adding engineering to our program gave immense benefits to all students but especially to those new to English.*

5.2 | Affordance 2

Engineering uses multiple modes to communicate including writing, drawing, and gesturing. Multimodal approaches invite ELs to demonstrate their thinking and participate in small group and classroom deliberations.

Engineers often rely heavily on sketches, mathematical equations, diagrams, physical models, and graphs as well as written text and oral presentations to explain their ideas and solutions (Blanco, 2003; Bucciarelli, 1994; Dym et al., 2005; Trevelyan, 2010). The array of tools and models also allows ELs in classrooms to be successfully engaged in the engineering activities of exploring, testing, and revising solutions. Displaying information multimodally supports receptive language. Regardless of their English proficiency, students can manipulate physical objects, and employ sketches and drawings to express their ideas (García & Kleifgen, 2018; Paugh et al., 2018). Students can demonstrate their capabilities and experience success. In this way, students are able to learn the substantive knowledge and practices of engineering (content) in ways that are not dependent on verbal language proficiency and also use other modes such as writing and drawing.

5.2.1 | Classroom example

Like engineers, students designing an electrical alarm circuit express their nascent ideas in a number of different ways. They manipulate bulbs and wires (physical artifacts) as they explore the components and how they work and try to illuminate a bulb. Then they draw their ideas and translate them to standardized schematics. As they debate where in the circuit to position a light bulb, they gesture to various locations on the physical model and on their sketches. Students draw, redraw, and debate what they have represented in the physical and sketched form. They trace the routes of the circuit as they challenge whether the system will function as expected and ask questions about how to connect the various elements (wires, bulbs, switch). As they engineer, they document their ideas in concrete depictions, gestures, and drawings, which they refer to as they justify and clarify their thinking. The team gradually captures thinking in more abstract forms, moving back and forth between modes as needed.

5.2.2 | Teacher testimonials

Engineering knowledge often emerges from a variety of physical and semiotic forms. Teachers explained that students who were ELs could participate in engineering teams because they were able to call on multiples modes of communication. Students can use types of discourses they are comfortable with—they may begin by expressing their ideas in their native language, through gesture, or through drawing, and then add spoken or written English as they need or learn it. Teachers also noted that students' desire to express their ideas spurs them to contribute to group discussions during engineering activities.

> *Students who are usually reluctant to speak in class usually participate more and are more confident [during engineering]. Students can show mastery of concepts through challenges that they may not show in speaking or writing. Students sometimes choose to speak in their native language or show ideas through drawings.*

> *Students can be active participants in an experiment without the need for any discussion. However, once they are engaged in an [engineering] activity, they often forget that they don't like to speak and get caught up in the experience while utilizing the new vocabulary they are learning.*

5.3 | Affordance 3

Engineering casts failure as an opportunity to learn. This creates an environment that fosters risk-taking among students. This orientation allows ELs to take risks linguistically and engage more actively with their peers.

An iterative engineering design process communicates to students that it is expected that their first attempt will not be the final one—they will be improving their work. Failure and productive risk-taking in engineering play an important role and should be embraced as a part of a process students learn from to inform subsequent attempts (Crismond & Adams, 2012; Johnson, 2019; Lottero-Perdue, 2015; Madhavan, 2015; Petroski, 2006). In engineering, failure during development is normalized and accepted. A culture where failure and risk-taking are recognized as part of everyday practice can carry over to interactions with the English language as well—students may become more comfortable taking linguistic risks and refining their communication in subsequent iterations and interactions.

5.3.1 | Classroom example

An engineer's first attempt at a design solution is rarely her last. She knows that high-quality solutions require iterative cycles, out-of-the-box thinking, and often multiple failed attempts. Engineering instruction needs to encourage students to take risks, analyze where and how they failed, and use that knowledge in a subsequent redesign (Johnson, 2016). For example, students who are engineering an environmentally friendly parachute and container system to aid–drop supplies from an airplane for victims of a natural disaster have much to learn through testing. They consider the criteria and constraints for the system such as package and parachute size and weight requirements, materials that can be used, cost, reusability, and durability. They generate an initial idea and assess it in light of specifications. Some designs will not meet basic requirements; at this point students redesign. Once a design clears the initial criteria check, students move forward to test it. As they drop the aid package system from a given distance, they observe its descent and collect data to determine whether their design functions as expected. Did the supplies reach the ground intact? Many early designs may fail the test. Teams then reflect on their data with the goal of understanding where tweaks might enhance performance. Sometimes they experiment with completely new ideas or innovative possibilities. As students' experiences develop their understandings about the aerodynamics and behavior of parachutes, how the landing affects the package contents, and the need for buffering impact, their designs improve.

5.3.2 | Teacher testimonial

Iterative cycles of engineering design and learning from initial failures provide contexts for students to engage in academics in new ways. In traditional instruction, failure has negative connotations and is something to be avoided. Engineering casts failure in a new light. Teachers remark that ELs are particularly adept at moving through and learning from attempts that initially are not "correct" because they have more experiences taking linguistic risks and learning through practice. Understanding that failure is something expected during engineering often encourages ELs to participate and take risks that can lead to improved designs.

> *[English learners] have worked hard at not being noticed, so they will not be called upon. Engineering designs are rarely correct on the first attempt and can always be improved. With everyone working on designs that don't always work puts the English learner at ease and they open up and begin to engage with others and become an active participant.*

> *It all ties into the even playing field. Mistakes are going to happen and it is all right. The term, "trial and error" is frequent. Everything can be improved and there are many ways to solve a problem. This eases the stress of "right/wrong" and allows English learners to be actively involved without worrying about what others will think.*

The success and persistence through failure that ELs experience during engineering challenges can build their confidence in other subjects. One teacher observed "that [EL] students build confidence in their learning through engineering activities, and this boldness transfers over to other subject areas." Another noted that ELs' experiences learning from unsuccessful attempts positioned them better than non-EL students to deal with failure during engineering challenges: "My EL students tend to have a better developed ability to acknowledge and then move on with new approaches as a response to failure than do my non-EL students."

5.4 | Affordance 4

In engineering, there are often multiple solutions given the criteria and constraints of a particular design challenge. The open-ended nature of engineering problems encourages diverse approaches and solutions. ELs can draw on their experiences as they generate ideas.

Many engineering problems are open-ended and allow for multiple solutions (Brophy et al., 2008). In the classroom, this facet is embraced by students, including ELs. They are motivated by the opportunity to apply their creativity and develop unique solutions. Like professional engineers, students should aim to optimize solutions; however, they must do so within specifications—designs need to adhere to a set of criteria and constraints (Anderson et al., 2010; Madhavan, 2015). A multiplicity of possible solutions invites students to learn from each other's ideas. The value placed on creativity and out-of-the-box thinking, the iterative nature of the engineering design process, and an array of "correct" solutions, all invite ELs to participate as team members (García & Wei, 2014). The array of brainstorming activities encourages ELs to share their experiences and ideas.

5.4.1 | Classroom example

Students working as environmental engineers are designing a process to clean a model oil spill. They learn about two approaches—containing the spread of oil or removing the oil. First, they investigate a variety of materials that include rubber bands, yarn, plastic spoons, pipettes, cotton balls, felt, coffee filters, sponges, and cheesecloth to determine how well each performs individually. They will use these materials to clean the oil from a model ecosystem (a criterion) and measure how much oil remains in both the water and on the shore. The constraints are presented; students learn how much each material costs and the overall budget allocated for the clean-up effort and are challenged to design the least expensive method possible. Each team develops its process for cleaning the oil. Teams select which materials they want to use, determine the degree of use (amount or frequency), figure out the order of operations, and calculate the cost. The array of items allows a wide variety of possible solutions. Students rely on their previous experiences and their creativity as they design a process. Then they use their process to clean a model oil spill, measure its effectiveness, learn from the results, and redesign. The multiplicity of ways this problem can be remediated supports diverse approaches. Some groups will spend money to contain the spill before they clean it. Others will decide to use all their financial resources to purchase the more expensive materials that absorb oil. As groups consider how to cut the cost of their solutions further, they will rethink the order and materials selected for their process.

5.4.2 | Teacher testimonials

Teachers identify the open-ended nature of the engineering challenges as a feature that invites ELs to participate. In engineering, the multiple approaches to a problem, multiple ways to express ideas, and multiple solutions encourage ELs to share what they know with their teams, as teachers expressed in their responses.

> *There are so many opportunities and possibilities to share ideas, possible solutions, conjectures and outcomes that are not strictly bound to linguistic principles. The excitement and engagement in learning for my ELs is so evident when one enters the room that it draws comments from many of our support staff.*

> *My students enjoy the open-ended aspect of the problems they'll be solving, and the hands-on experiences really allow the language to become concrete. This allows them to better share their thinking, but if they are having difficulty with the language to tell about their ideas, the hands-on aspect allows them to show their ideas. Because there are multiple ways to solve a problem, they feel success when they solve a problem, but also feel happy for others' success as well. I had one student who was very limited in his English language, but when faced with a task to create something to solve a problem, he was the first to successfully complete the task in his group. It made him feel proud, and it let others in the group see that he had lots of knowledge, he just wasn't able to express it in words.*

5.5 | Affordance 5

Successful engineering design solutions benefit from diverse perspectives. Engineering encourages students, including ELs, to draw from their life experiences and consider their personal backgrounds as assets when imagining and designing solutions.

Engineering solutions are strengthened when a diversity of ideas, perspectives, and approaches are applied to the problem (National Academy of Engineering, 2002). A hallmark of engineering is innovative thinking.

Bringing a multiplicity of ideas to brainstorming and iteration often results in stronger solutions. Students from varied backgrounds can contribute different ways of thinking about a problem that are informed by their experiences and their cultural knowledge (González et al., 2005; Wilson-Lopez et al., 2016).

5.5.1 | Classroom example

Designing a better play dough is something chemical engineers might tackle. Students can work on this challenge as well—combining flour, salt, and water in different proportions until they design a recipe (or process) for a dough that is not too sticky or too dry and malleable enough to hold its shape. Traditional play dough uses wheat flour. Students can extend an engineering challenge by drawing on familiar knowledge and resources. For example, one bilingual fourth grade class compared wheat flour to corn flour as many of the Mexican and Central American students used corn flour at home (Cunningham, 2018). Allowing students to use materials they had access to encouraged them to continue to engineer new solutions outside of school with family. Many brought samples or processes they had developed at home to share with the class, prompting a discussion about the properties and merits of each type of flour.

5.5.2 | Teacher testimonials

Teachers identified ways that students drew from their own personal experiences to offer solutions to engineering problems. In these examples, teachers recount how ELs' backgrounds provided knowledge they shared to enhance the classroom's understanding. Connecting the engineering problem to their lives also motivated students to propose solutions.

> *The exciting part about engineering is that language is not necessary to participate. Students from other regions of the world have their own experiences and their newfound knowledge can be added to mix when they are teamed with others. Living in an area that is landlocked, I have had students come from areas where they were surrounded by an ocean. Their knowledge of sand and the effects of waves was beneficial in determining which soil type to use to build a structure.*

> *There have been many times where students have been able to connect with the curriculum [that used engineering examples from around the world] because they were personally invested in the problem because that's either where they lived, that's where their family still lives, or they were problems that affected them. When designing packages for international food drops, one student shared about what it was like to live in Thailand and what the monsoon season was actually like. When designing walls, students connected with the fact that many of their families are trying to grow family gardens with plants from their home countries and are trying to keep out the deer and rabbits.*

5.6 | Affordance 6

Features of engineering (multiple solutions, learning from failure, materiality, communication using symbols such as a circuit diagram) foster ELs' success and encourage them to become more active members of the learning community during engineering projects. Consequently, they themselves, their teachers, and their peers have an opportunity to see ELs in a new light.

Many of the features of engineering discussed above allow ELs to engage more fully in engineering lessons. They can participate as active members of their group and class as they contribute their ideas. They can also share designs that show that they are creative and smart. Such substantive and meaningful interactions with their peers and the engineering task help students develop confidence in their ideas and themselves as problem solvers and engineers (Anderson et al., 2010; Capobianco et al., 2012; Carlone, 2017). Through such interactions, classmates also recognize the strengths that ELs bring to engineering activities.

5.6.1 | Classroom example

Engineering activities that include multiple solutions, iterations, approaches, modalities, and discourses invite increased participation by students with diverse approaches and perspectives. Introducing a new subject whose lessons differ from traditional activities can shake up classroom norms and hierarchies and encourage students to view their own, and their peers', abilities differently (Hegedus et al., 2014). For example, in a class engineering insulation for a solar oven, students were challenged to think about which materials they might use and how they might be arrayed inside a shoe box to maximize the capture and retention of heat energy. The design that performed best during tests was created by a student who had not flourished during traditional academic lessons. His classmates quickly recognized that his innovation—gluing cotton balls to the box lid—was highly effective. It was adopted by other groups in the class during a redesign cycle and he was identified by his peers as a great engineer.

5.6.2 | Teacher testimonials

Engineering provides opportunities for ELs to demonstrate their knowledge and expertize in ways that do not have to be language-dependent. They can enthusiastically engage as active group members as they contribute their ideas. One teacher commented, "I am often surprised by how eager my ELL students are to engage in engineering activities, even though they are usually very quiet during other activities in science." Sharing their ideas and designs shows that ELs are creative and smart. Teachers' remarks highlight that such substantive and meaningful interactions with peers and engineering tasks develop EL students' confidence in themselves and their ideas. During engineering lessons, classmates also recognize the strengths that ELs bring.

> *When a student's ideas are praised and their success applauded, they feel a sense of pride. This is essential for English learners because they already feel different and inadequate. Engineering projects allow them the opportunity to show others what they are capable of doing without the stress of verbally having to convey their thoughts. They can just show and demonstrate what their design should do. This allows others to celebrate their success with them. It is a win–win situation for ALL!*

> *Engineering activities allow the EL students to really show that they have equal creativity, science/STEM understanding of concepts and application of skill/practices. Sometimes EL students are perceived as having fewer abilities in school… so often engineering activities allow them to shine, with boosts to their confidence, peer perceptions, and enjoyment of school! They remember the vocabulary because it has meaning for them in a successful situation.*

> *Two years ago, Rashid [researcher-created pseudonym] came to our class from Pakistan speaking no English. I was convinced that he had retained little to no academic information all year. In the second week of the…package engineering [unit in which students designed a parachute to protect aid*

supplies that were being dropped], the class came to a complete standstill when we heard someone shout, "NO!!! NO!!!" Rashid went on to explain through hand gestures and some English, "No! Need two (two fingers held up) poof, poof (meaning parachutes)! No poof, poof (again meaning parachutes and using hand gestures) go splat (he hit his fist against the table) and all break. No good! REDO!!!" It was the most English anyone in the class had heard him put together to create an entire thought in the entire year. One of the other students in his group asked him to explain again and to sketch a model of his redesign. The group ended up labeling the new design, practicing the words, redesigning their package and testing a much more successful iteration. Engineering enabled Rashid to shine. It didn't matter that he didn't know all the words, he was able to utilize the hands on, real world engineering challenge to express his ideas and grow as a learner.

5.7 | Across affordances

In the classroom, students experience the intertwined affordances in different combinations that depend on engineering activities. The contexts of solving problems provide varied affordances for different students as the activities unfold. The nature of engineering, including the physicality of the devices, multiple modes of communication, the need for teamwork, alternative solutions, and drawing from previous experiences and knowledge, can structure educational experiences that benefit ELs as teachers articulated.

In my experience, engineering activities are a crucial component of the curriculum for all students, particularly ELs, because engineering encourages students to problem solve, observe, question, create, and collaborate. This enhances conversational language skills, boosts relevant academic vocabulary, and builds a common experience of productive struggle.

Engineering and design principles, by nature, provide all students with the opportunity to explore situations, test solutions to problems and refine their results. Very often, the models or mock-ups we explore cross linguistic barriers which, in my classroom, go beyond language differences, often also involving issues with literacy…. Students were called upon to collaborate and communicate, in words and through modeling. The quality of engagement and the willingness to commit beyond easy outcomes were byproducts of their authentic investigations. My EL students ended the [engineering] unit with much stronger communication skills, academically and socially. Their confidence and comfort levels increased. They were able to share learning and ideas beyond typical pencil and paper methods.

6 | SETTING A RESEARCH AGENDA FOR INCLUSIVE ENGINEERING EDUCATION AT THE ELEMENTARY LEVEL

This paper proposes a set of hypothesized affordances for engineering with ELs. We generated these based on relevant literature, extensive work with teachers, classroom observations, and exploratory surveys of EL teachers' experiences. However, such affordances need to be examined in more depth and pressure-tested with empirical research. Doing so will identify ways that curricula, instructional strategies, and teacher professional learning can be designed and implemented to enhance educational opportunities. Here we discuss a few general directions for further study and invite researchers to craft specific questions within these general domains.

6.1 | Strategies for curriculum, instruction, and assessment

To support language development and engage students in engineering, curriculum can be designed to create social situations that make use of epistemic practices and tools that support learning. Our and others' previous research (Hertel et al., 2017; Jordan & McDaniel, 2014; Kelly & Cunningham, 2019; Watkins et al., 2014; Wendell et al., 2019) identified the ways students can engage in epistemic practices of engineering and employ epistemic tools through the engineering design process. Realizing affordances for ELs will depend on the ways that curricular features offer opportunities for students to engage in productive discourse, use multiple modes of communication, provide reasons and audiences for conversations about engineering and science, and participate actively with classmates around substantive science and engineering topics. The *English Learners in STEM Subjects* report's (NASEM, 2018) fourth recommendation, "Develop high-quality science, technology, engineering, and mathematics (STEM) curricular materials and integrate formative assessment into classroom practices to both facilitate and assess English learners' (ELs') progress" (p. 6), highlights the important role that materials play and the need for development of new resources.

Curriculum and instruction co-occur and should be well aligned and informed by embedded assessments of knowledge. To examine the affordances of engineering with ELs, a number of issues need to be researched. Importantly, curricula need to consider the learners, including the knowledge base and competencies brought to the situation from the learners' previous experiences and cultural backgrounds. Although engineering design offers a number of ways for students to draw on their knowledge, communicate what they know, and participate with others, curricula need to draw from, and foster, the funds of knowledge available to be employed to solve the engineering problems. Instructional strategies also need to reflect the diversity of the learners.

A key feature of authentic discourse during engineering design is the common basis for decision making. Engineering activities and lessons can be designed to allow for multiple solutions, while developing a common basis for evaluation of solutions. In this way, shared data sets, learning across student groups, and iterating designs on collective evidence, can both foster discourse and lead to improved engineering (Kelly & Cunningham, 2019). By adhering to a common set of criteria, students can be held accountable to empirical results and each other. Through these processes, engineering design solutions use and enhance scientific knowledge and practices. Thus, curricula, instructional strategies, and assessments need to be examined to ascertain the affordances of asset-based orientations to education.

6.2 | Students' knowledge, participation, and identity

A second focus of the overall research agenda should study student characteristics. Students bring knowledge to engineering and other academic tasks; this knowledge can transform and change over time through learning processes. The affordances of engineering nurture students' conceptual understanding of engineering and science, knowledge of how to engage in reasoning and practices, and development of academic language. Engineering offers the potential for knowledge to be evident in multiple modes including instantiation in constructed technologies, signs and symbols, gestures, and other discourses. These manifestations of knowledge offer the potential to learn about students' sense-making and reasoning but also pose research challenges as studying such knowledge may require capturing the full range of students' physical and semiotic activity. Such considerations are particularly important when research focuses on ELs or other students who may benefit from linguistic supports.

Engineering, like science, is social knowledge that requires working with others and learning how to participate in groups to accomplish common goals. Our affordances rest on assumptions about how classrooms should be structured to invite all students to engage in purposeful activity. For example, engineering problems often start by identifying the needs of a client. Throughout the engineering design process, considerations of the client, criteria and constraints, and optimized solutions necessitate team members to interact in organized, goal-directed activity.

By allowing students to draw from previous knowledge and experiences and communicate in a variety of modes, students, particularly ELs, can be productive members of their engineering team. A robust research agenda needs to include close analysis of the participation structures and ways students interact and contribute in small group and classroom settings. Such participation also invites students to consider their capabilities and those of their classmates in new ways.

Authentic, meaningful participation in engineering activity coupled with reflective conversations can also spur students to reimagine and expand their conceptions of themselves as learners and engineers (Kelly et al., 2017). In this way, the development of students' academic identities is constructed through their everyday experiences in ways of talking and being in their educational settings. Engineering invites multiple types of engagement and expertise, for example, carefully assembling a device, creating a three-dimensional diagram, drawing on cultural knowledge, and/or writing persuasive text. Thus, a research agenda that considers affordances for ELs needs to take into account multiple ways participation in discourse fosters possible identity constructions. Such studies should not only consider individual's constructions of their identities, but also explore how identity of a social group morphs over time and how students and teachers reconceptualize each other's strengths and emerging identities.

6.3 | Teacher professional development

Teacher knowledge of curriculum, students, subject matter, instructional strategies, and teaching ELs are important in any domain. There has been an increasing body of research that focuses on inservice and preservice professional development for science and mathematics teachers of ELs (Buxton et al., 2017; Chval & Pinnow, 2010; Shaw et al., 2014). Findings from this paper have much potential to inform the emerging research agenda in K-12 engineering education related to professional learning. To effectively capitalize on the affordances described above, teachers need new understandings both of engineering as a discipline and ways that ELs can participate in the academic discourses of science and engineering. Engineering is a relatively new discipline to K-12 education with unique features that can be welcoming to ELs. As we describe above, engineering offers opportunities for multiple solutions, learning from failure, and collective decision-making. Teachers need to understand these aspects and how to structure instruction to encourage full participation by all students.

These disciplinary aspects of engineering can only afford ELs enhanced educational opportunities if teachers develop rich strategies for how to engage all students in classroom activity and discourse. Research should examine ways teachers learn from and about all of their students, especially ELs, and their potential to contribute to engineering. Teachers need to become familiar with instructional scaffolds, tools, and social groupings that enable ELs to demonstrate their ability to contribute ideas and solutions. For example, inviting students to use multiple modes of communication when they engineer makes visible students' ideas and knowledge. A robust research agenda would examine how professional teacher learning can incorporate activities and strategies that foster asset-based pedagogies in teachers.

6.4 | Ecology of schooling

Teachers and students exist in a larger school and societal ecology. Decisions about policy, curriculum, assessment, workforce, and course taking all influence educational opportunity for students, including ELs. The affordances we describe can be differentially constructed depending on the ecological features of the setting. For example, the affordances of engineering can be recognized if ELs engage in engineering activities rather than being pulled out of their science and engineering classrooms for additional language support. As we described in the previous sections describing the research agenda, the value of engineering for ELs depends heavily on the classroom culture.

A robust research agenda on this topic needs to take into consideration national, state, and school policies; the overall assessment regimes; curricular decisions of states and districts; and specific discourse features of classroom instruction.

6.5 | Research considerations for actualizing affordances of engineering for ELs

Although we recognize the robust research agenda we describe above proposes important questions, such research needs to attend to challenges and constraints. We recognize four such of these. First, and importantly, our focus has been on students—their potential for learning and the consequence of offering equitable educational opportunities. To understand students' knowledge and sense-making as they engage in engineering (and other academic subjects), studies need to examine students' talk and action in detail and over time. Such research can be labor-intensive and difficult to organize given the vagaries of research and schools. Second, assessment strategies are often highly reliant on academic language of a particular sort. We have argued in this paper that engineering (and potentially other subject-matter areas) can offer affordances for learning and ways for students to demonstrate their knowledge through multiple modes. Research studies that examine engineering activity are more robust when they capture verbal exchanges, gestures, diagrams and schematics, and construction of technologies. Accordingly, such data sets are detailed and highly contextualized. Third, engineering requires students to engage in a range of cognitive processes. Problem solving, communication across multiple audiences, reliance on science, testing to collect empirical data, and analyzing and arguing from such data require divergent thinking. The assessment of student cognition in these settings can be time consuming, complex, nuanced, and the value of engineering is likely to be missed by simple measures of assessment. Finally, in the United States and many other countries, children bring a wealth of languages to school. These languages and cultural experiences provide rich assets that can be drawn into educational experiences. If researchers are to examine issues such as the value of translanguaging during engineering lessons, for example, they will need to access resources that enable them to more fully understand what children are saying and doing (e.g., by translating students' conversations, talking with members of the cultural communities, and welcoming students' multiple modes of expression). Because students in many classrooms in the United States speak a variety of languages, such work will need to be done with and for the languages and cultures that are represented.

Engineering solutions are strengthened by a diversity of ideas and perspectives. ELs are one of the fastest-growing populations in elementary schools and bring with them an array of experiences. By creating engineering activities and classroom environments that foster equity and provide opportunities for participation by all students, we can help ELs learn engineering disciplinary knowledge, productively use and develop academic discourses, and recognize themselves as engineers. Realizing this vision will improve not only engineering, but many academic disciplines and will affect not only ELs, but all students.

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