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Introduction

Marked ethnic, linguistic, and racial disparities in elementary, secondary, and college students' STEM (science, technology, engineering, math) preparation and achievement (Lord et al., 2009; Muller, Riegle-Crumb, Schiller, Wilkinson, & Frank, 2010; Riegle-Crumb & Grodsky, 2010) suggest a need to integrate STEM curricula with pedagogical approaches that address the needs of linguistically and culturally diverse students, especially those of the growing English learner[1] student population (Garcia & Jensen, 2007). Despite the fact that English learners (EL) are the fastest growing K-12 population in the United States (Fong, Bae, & Huang, 2010; Jiménez-Castellanos & García, 2017; Kim & García, 2014), only 27% of teachers in a national survey reported receiving any professional development related to EL instruction (National Center for Education Statistics, 2012). Likewise, 15% of English learners receive no linguistic support services whatsoever (Wolf, Herman, & Dietel, 2010). For the most part, mainstream classroom teachers instruct English learners in STEM content in English with little, if any, pedagogical reinforcement (National Academies of Science, Engineering, and Medicine, 2018; Santos, Darling-Hammond, & Cheuk, 2012).

In view of this, this study is part of a larger project that trained teachers in the use of a new EL-focused engineering curriculum for grades K-5, designed to address English learners' STEM literacy while simultaneously developing their English proficiency. The project built on prior research from two distinct fields: bilingualism and engineering systems thinking. Specifically, we endeavored to

[1]English Learners (ELs) are the subgroup of bilingual students, those who speak a language other than English in the home, who the school has determined to require linguistic support services in order to successfully access core academic content.

capitalize on bilingual students' *problem-solving advantage*, which refers to bilingual students' approach to every situation from various (linguistic) perspectives (Bialystok & Majumder, 1998; Secada, 1991). This parallels a key mindset and perspective in engineering of assessing and considering a problem from multiple angles, otherwise known as *systems thinking* (Chan, 2015). The larger project (Callahan & Crawford, 2015) was designed to bridge STEM and EL instruction and broaden English learners' participation in our nation's STEM pipeline. More specifically, the project's engineering lessons incorporated principles from established frameworks for quality K-12 engineering education (Moore et al., 2014) and were designed to prompt teachers to maximize collaboration, communication, and systems thinking among their students in order to facilitate English learners' English proficiency development while strengthening their STEM engagement and efficacy.

Prior research has demonstrated the potential of gesturing to benefit English learners' second language acquisition (McCafferty & Stam, 2009), suggesting that teachers' gesturing during engineering and STEM instruction for ELs merits empirical consideration. In the present study, the focus is on the implicit and explicit use of gesturing, as one aspect of potentially effective EL pedagogy, during elementary school engineering and science instruction. This exploratory comparative analysis highlights first, differences in teacher gesturing between science and engineering instruction; and second, how engineering and STEM instruction might incorporate linguistically sensitive teaching practices. Therefore, we explored the following research questions:

1. What types of gestures does an elementary school teacher enact, and with what frequency do they occur during engineering and science instruction?
2. What, if any, differences exist in the type and frequency of the gestures enacted by the elementary school teacher during engineering and science instruction?

Literature Review

Gesturing and Primary Language Development

Prior research suggests that gesturing plays a fundamental role in the development of children's modes of communication, including their primary language. In fact, research has illustrated how early language development is a complex process that draws from multiple inputs, linguistic as well as physical. Goodwyn, Acredolo and Brown (2000) showed how the use of gestures and other physical actions in early communication parallels and even precedes the trajectory of "distancing" *symbol* (i.e., the communicative input such as words, and signs) from *referent* (i.e., the concept being communicated) in verbal language development (p. 82). That is, young infants, (i.e., approximately 10 months old) begin to use deictic gestures (i.e., reaching, pointing) to communicate what they want, while older children (3-5 years) use sophisticated representational pantomimes (i.e. physically representing a situational action without having concrete or substitute representation of an object). For example, producing the motion of opening a door without using any objects and only one's hands to communicate actions done with objects. In so doing, it appears that children may no longer need concrete symbols in their physical representations by this developmental stage (Boyatzis & Watson, 1993; Goodwyn et al., 2000). Ultimately, Goodwyn and colleagues (2000) found symbolic gesturing to facilitate early verbal language development in young children (i.e., approximately 11 months to three years). The authors posited that gesturing might serve as a scaffold to verbal communication, a more complex modality, possibly accounting for some of the advantages observed among young children assigned to the Sign Training treatment (Goodwyn et al., 2000). These findings complement earlier work suggesting a significant relationship between symbolic gesturing and oral language development (e.g., Acredolo & Goodwyn, 1988; Iverson & Goldin-Meadow, 2005; McCafferty & Stam, 2009).

Gesturing and Second Language Acquisition

Prior research has also extensively examined the value of gesturing and other physical movements in second language acquisition (e.g., Asher, 1966, 1969; Lazaraton, 2004; Mavilidi, Okely, Chandler, Cliff, & Paas, 2015; Nicoladis, Mayberry, & Genesee, 1999; Toumpaniari, Loyens, Mavilidi, & Paas, 2015). Stemming in part from early primary language development research with infants, Asher's seminal Total Physical Response (TPR) model (1966, 1969) postulated that second language instruction should also incorporate similar pedagogical models to those of primary language development, particularly a stress-free and relaxing environment in which the focus is on meaning through the use of physical movement and real-world objects (Smith-Walters, Mangione, & Smith Bass, 2016). Repeatedly, researchers have found that young children who receive either foreign (i.e., English in Japan) or second (i.e., English in the U.S.) language instruction that incorporates physical activity and/or gesturing outperform language learners who receive speech-only instruction (e.g., Mavilidi et al., 2015; Smith-Walters et al., 2016; Toumpaniari et al., 2015; Wang, Hwang, Li, Chen, & Manabe, 2019).

Findings like these have also proven consistent across an array of languages and language learning contexts (e.g., Mavilidi et al., 2015; Nicoladis et al., 1999; Toumpaniari et al., 2015). Notably, in a study of bilingual French and English language-learning infants, Nicoladis and colleagues (1999) found that young infants mirror adult patterns and frequencies of gesturing, but most importantly, that the types of gesturing produced by language learners could correlate with their stage of language proficiency development. Indeed, Lazaraton (2004) argued that nonverbal behavior is a fundamental aspect of teaching second language learners, and that gesturing provides an important form of comprehensible input. Given the relatively nascent examination of gesturing in the context of second language and disciplinary content learning, we propose that gesturing may be an essential form of comprehensible input (Krashen, 1981, 1982, 1985). In the following section, we examine the literature regarding teachers' practices framing content for second language learners.

Potential of Gesturing in EL Pedagogy and Practice

Language and educational policy charge teachers with developing English learners' academic proficiency in STEM content at the same time they are learning English (Hakuta, 2011). Nationally, the No Child Left Behind Act (NCLB, 2001), and its successor, the Every Student Succeeds Act (ESSA, 2015), focused educators' attention on English learners' STEM achievement for the first time (Cosentino de Cohen, 2005), with the recent standards movement (Next Generation Science Standards Lead States, 2013) reinforcing the importance of teachers' EL and STEM capacity (Lee, Quinn, & Valdés, 2013). EL instructional efficacy is particularly challenging as teachers must simultaneously develop students' English proficiency and content area expertise (Téllez & Waxman, 2006). However, even when teachers feel confident in their STEM knowledge and instructional abilities, they often fail to address issues of cultural and linguistic diversity, which in turn minimizes English learners' STEM experiences (Lee, Maerten-Rivera, Buxton, Penfield, & Secada, 2009). It is not enough to simply employ good teaching practices and expect English learner achievement to improve (De Jong & Harper, 2005). Instead, EL instructional efficacy reflects a teacher's ability to contextualize the language constructs that English learners must master (Bailey, 2007; Shin, 2009). Importantly, teachers must be able to call out and address the linguistic nuances specific to each academic content area

(Lee, Quinn, & Valdés 2013, Valdés 2001; Turkan, de Oliveira, Lee, & Phelps, 2014). This becomes of greater importance as the EL performance gap is defined not just by language acquisition, but also by content area mastery (Cosentino de Cohen, 2005; Fry, 2007; Valle, Waxman, Diaz, & Padrón, 2013).

Research has found that pedagogical approaches that simultaneously integrate literacy and science instruction produce significant gains in students' science achievement (Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012). Offering language experiences through inquiry-based instruction may be one of the more effective practices for improving EL instruction (Stoddart, Solis, Tolbert, & Bravo, 2010). Engineering instruction in particular may lend itself to improving teachers' EL instructional efficacy due to its emphasis on open-ended design challenges, collaboration, communication, and systems thinking (Katehi, Pearson, & Feder, 2009), all features typically endorsed as rigorous and effective EL pedagogical approaches to content area instruction (de Oliveira, Obenchain, Kenney, & Oliveira, 2019; Verplaetse & Migliacci, 2017). As such, we argue that it is important to identify specific teaching practices that can both improve language instruction and make STEM content more accessible to English learners.

The role of gesturing in STEM instruction also pose important implications in efforts to adopt more culturally responsive teaching practices. Culturally responsive teaching (CRT) not only values diverse students' cultural attributes, features, experiences and perspectives, but also incorporates them into instructional practice for improved outcomes (Gay, 2002). CRT is predicated on the idea that learning is enriched, heightened, and facilitated when students are not only given opportunities but encouraged to access academic content from their "lived experiences and frames of reference" (Gay, 2002, p. 106). As such, one core feature of CRT is the notion of *cross-cultural communications*, which emphasizes the need for teachers' ability to be sensitive to their ethnically diverse students' communicative codes and to utilize them to help their students succeed (Gay, 2002). Of course, one key feature of these codes are gestures, as Gay (2002) explains:

> Culturally responsive teacher preparation programs teach how the communication styles of different ethnic groups reflect cultural values and shape learning behaviors and how to modify classroom interactions to better accommodate them. They include knowledge about the linguistic structures of various ethnic communication styles as well as contextual factors, […] *gestures* [emphasis added] and body movements. (p.111)

Thus, as Gay highlights above, effective cross-cultural communications between teacher and student are dynamic and multifaceted in nature, involving a comprehensive understanding and reciprocation of all modes of communication, including embodied modes, with respect to the cultural community of interest.

Accounting for these rich and diverse perspectives informing EL educational policy, STEM instruction as a context for literacy instruction, and culturally relative pedagogies, in the present study, we examine teacher gesturing in the context of engineering instruction. In particular, in the present study, we focus on the potential of engineering and gesturing within engineering, to improve English learners' STEM experiences.

Theoretical Framework

Krashen's (1982, 2009) input hypothesis postulated that the acquisition of a second language requires, in part, for the learner to receive considerable and understandable linguistic input, or comprehensible input. Receipt and processing of comprehensible input in turn leads to an internal development of grammatical structures and overall fluency in the learner (p. 22). The main idea behind such hypothesis is to provide the second language learner with enough varied, understandable linguistic exposure, similar to first language development, such that a natural language acquisition process develops that will lead to proficiency. We overlay McNeill's (1992) gesturing framework as the essential link between speech sounds and gestural movement that facilitates comprehensible input. In short, we argue that gestures' fundamental connection to linguistic communication makes them critical to the comprehensible input process as defined by Krashen (1982, 2009). For the purposes of the present inquiry, we adopted McNeill's (1992) gesturing framework as our theoretical lens when exploring teacher gestures.

McNeill (1992) initially classified gesturing into four major categories that, depending on the nature of the gesture, dictate the relation between the gesturing production and the content of one's speech. These gesturing categories included: (a) *deictic* (pointing) gestures, which call attention to objects, both concrete and metaphorical, and are typically performed with the index finger, (b) *iconic* gestures, which represent semantic content including kinetographic gestures (e.g., "sweeping" the floor or "driving" a car), and pictographic gestures (e.g., outlining the shape of a box or other physical objects), (c) *metaphoric* gesturing, which, similar to iconic gestures, represent semantic content but now symbolizing abstract ideas, and 4) *beat* gestures, which serve as a visual representation of the rhythm being produced by one's speech (Lazaraton, 2004, p. 76). As individual gestures often encompass elements of multiple categories, McNeill (2005) updated this theory to frame these as four related, rather than mutually exclusive, dimensions.

Methods

Case Study Context and Participant

Data for this study were collected as part of a larger ongoing research project designed to examine how professional development in and implementation of an EL-focused, K-5 engineering curriculum might inform how teachers supported English learners' linguistic capabilities through collaboration and systems thinking. Drawing on seminal research detailing the bilingual advantage (Bialystok & Majumbder, 1998; Secada, 1991), the curriculum was designed to optimize the relationship between English learners' problem-solving skills (Greenberg, Bellana, & Bialystok, 2013; Prior & MacWhinney, 2009) and engineering habits of mind (Katehi et al., 2009) which emphasize systems thinking, collaboration, and design, and require sophisticated creative and critical thinking skills (Chan, 2015; Katehi et al., 2009; Razzouk & Shute, 2012). Project implementation took place in an elementary school located in the Southwestern United States that enrolled fewer than 15 percent English learners and offered primarily integrated English as a Second Language (ESL)-services in English-only instructional contexts. All school site teachers were required to address English learners' linguistic development within their daily lessons; the school offered no discrete ESL instructional services.

During the initial phase of the project, the research team invited the six participating elementary teachers (one per each grade level) to participate in multiple, individual semi-structured interviews, as well as professional development workshops before, during, and after the completion of their implementation of the EL-focused, K-5 engineering curriculum. Furthermore, the research team asked the teachers to record themselves as they taught one science lesson and up to nine engineering lessons over the course of the school year (2016-17). Here, we focus our inquiry on one of the six participating teachers, Ms. Collins (a pseudonym).

Aligned to our exploratory case study approach, we focused our analyses on Ms. Collins, a female kindergarten teacher with over 10 years of teaching experience. Additionally, we selected Ms. Collins as a focal participant due to her extensive teaching experience and ESL certification, which we hoped would provide compelling gesturing data. Furthermore, as prior research has shown that gesturing provides an important scaffold to young children's language development (Acredolo & Goodwyn, 1988; Gu, 2015; Kuhn et al., 2014; Nicoladis et al., 1999), Ms. Collins' kindergarten students (approximately 5-6 years old) would all be in the process of English literacy development, either as a first or second language.

Data Collection Procedure

As part of the larger research project, Ms. Collins received video-recording equipment (i.e., two video cameras, four memory cards, and a camera stand), and recorded as many of her engineering lessons as possible. It is important to note that our research team did not intentionally set out to study gesturing in and of itself. As such, Ms. Collins was not aware that her gesturing in particular would be of interest. Only after reviewing over six hours of our participants' instructional footage did we elect to focus our gesturing inquiry on Ms. Collins in particular. As such, we are confident that the gesturing Ms. Collins enacted during her lessons was not related to the presence of the larger project at her school site or in her classroom.

Ultimately, Ms. Collins recorded and archived a total of nine engineering lessons and one science lesson. As recommended by Jewitt (2012), we adopted an exploratory microgenetic approach (Miller & Coyle, 1999) in which the researcher minutely analyzes short segments of video data. In our case, this facilitated a deeper analysis of teacher-enacted gesturing, or teacher-gesture, as well as the exploration of within-subject variation of teacher-gestures between their science and engineering instruction. Because of this, data included the video-analysis of two full lessons from Ms. Collins: 1) a science lesson that involved the exploration of force and motion through the use of manipulatives, and 2) an engineering lesson entitled "Materials: Our Material World," that involved the identification of engineering materials and why/how these can be used for the creation of structures. Together, the two lessons yielded approximately 60 minutes of video data.

Analytic Approach

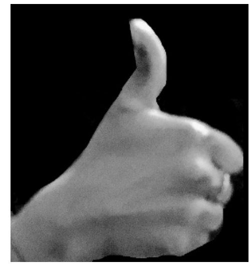
Coding schema. We utilized McNeill's (1992) gestural dimensions framework in order to code the gestures observed in the video data. McNeill (1992) identified four related dimensions of gestures: a) iconic, b) metaphoric, c) beat, and d) deictic (pointing). In later works, McNeill (2006) also identified a fifth dimension: emblems. Emblematic gestures symbolize culturally embedded understandings (for example, a "thumbs up" to indicate approval). Table 1 explains the qualities of each dimension.

McNeill (2006) is careful to describe the aforementioned dimensions not as rigid categories, but as points along a continuum; within any one unit of gestural production, elements of the other four can be observed simultaneously. While we generally identified the most evident or apparent dimension in a gesture, in some instances an observed gesture comprised multiple dimensions. In these instances, we coded these gestures to all of the most evident dimensions. Table 1 provides descriptions of each gestural dimensions.

Table 1. *McNeill's Gesturing Dimensions and Descriptions.*

Dimension	Description	Sample Image Depiction
Iconic [i]	"Iconic gestures that closely relates to the semantic content of speech [...] Iconic gestures may be *kinetographic*, representing some bodily action, like sweeping the floor, or *pictographic*, representing the actua form of an object, like outlining the shape of a box" (Lazaraton, 2004, p.84).	
Beat [b]	"Beats are gestures that have the same form regardless of the content to which they are linked. In a beat gesture, the hand moves with a rhythmical pulse that lines up with stress peaks of speech. A typical beat gesture is a simple flick of the hand or fingers up and down, or back and forth, the movement is short and fast. Although beats may serve a referential function, their primary use is to regulate the flow of speech" (Lazaraton, 2004, p.84).	
Metamorphic [m]	"Metaphoric gestures may be pictographic or kinetographic like iconics, but they represent an abstract idea rather than a concrete object or action. An example is circling the finger at the temple to signify the 'wheels of thought'" (Lazaraton, 2004, p.84).	
Deictic [d] (Pointing)	"Deictic gestures have a pointing function, either actual or metaphoric. For example, we may point to an object in the immediate environment, or we may point behind us to represent past time" (Lazaraton, 2004, p.84).	
Emblematic [e]	"'Emblems' are conventionalized signs, such as thumbs-up or the ring (first finger and thumb tips touching, other fingers extended) for 'OK', and others less polite. [...] Emblems or quotable gestures are culturally specific, have standard forms and	

significances, and vary from place to place. [...] These gestures are meaningful without speech, although they also occur with speech. They function like illocutionary force markers, rather than propositions, the mode of gesticulation, and the timing when they occur with speech, being quite different." (McNeill, 2006, p. 58).



Video observations, coding, and agreement. After all video data were collected, the research team met first to review the video data, identify the type and frequency of gestures, and then later to discuss, articulate, and clarify the data-analysis processes and coding schema. Before viewing and coding the science lesson video, the team clarified the qualifiers for each dimension of McNeill's (1992) gesturing framework, discussing inclusion and exclusion criteria for coding (see Figure 1). The research team participated in a round of blind coding, wherein they independently categorized all the gestures present in the video data without sharing perceptions of the gesture type. This initial round led to an inter-coder agreement of 83.74% for the classification of all 93 identified gestures, with a Cohen's kappa statistic of 0.84. After the initial round of blind coding, the team met again to reconcile any discrepant codes, discussing until reaching consensus for each gesturing instance.

Figure 1. *Sample Image of Data Analysis*

Time-Stamp	Description of Gesture	Coder 1	Coder 2	Reconciled Codes
0:11:00	"put your labcoats on" with elbows bent and raised near shoulder, alternates moving arms from back to front as if she were putting on an invisible coat (gesture imitates the same motion one would have when putting on a coat).	iconic	iconic	iconic
0:13:00	"put your name tag on" one hand held in open flat palm facing her chest, moves palm and touches it to one side of upper chest beneath the shoulder (as if she had an invisible sticker nametag).	metaphoric	iconic	iconic
0:14:00	"wear your safety glasses' with both hands in the shape of a C (or as if holding a pair of large goggles) starting from in front of her chest moves them up to either side of eyes.	iconic	iconic	iconic
0:21:00	"today we're talking about movement"--with palms facing up and fingers spread apart, moves both wrists in a semi arc in front of her chest	metaphoric	metaphoric	metaphoric
1:23:00	counts with fingers	emblematic	emblematic	emblematic
1:31:00	"shhh" index finger to lip	emblematic	emblematic	emblematic
1:39:00	"moving our bodies" moved open-palm hands near chest	iconic	iconic	iconic
1:43:00	"...you gotta listen though" palms facing down, moves both hands down coming to an abrupt stop	metaphoric	metaphoric	metaphoric
1:45:00	"after our dance" one hand with fingers closed with thumb that moved to center of cupped palm of other hand	metaphoric	metaphoric	metaphoric

Inclusion and exclusion criteria. In accordance with McNeill's (2006) framework, we coded anything involving representations usually made with the limbs, particularly arms and hands, but also inclusive of other body parts as gestures. We included both "empty-handed gestures where an object did not play an integral part" (Nicoladis, et al., 1999, p. 516) and instances where the teacher might have been holding an object *while* gesturing, but not instances in which the teacher was performing an action or motioning with an object that she had in hand.

As our research interests focused on Ms. Collin's content delivery and general teaching strategies, we opted to include only gestures that were visible to the whole group. That is, we did not code for gestures produced during individual or side interactions with either a single student or a small group. In addition, these individual or small group interactions were not reliably or clearly captured on video, all of which led to the elimination of seven gesturing incidents from our total corpus. Our final analytic sample included 86 gestures in total. We included gestures intended to either manage whole-class/large-group behavior or explain procedural information, as well as gestures that occurred in the context of content-driven discussions.

Post-coding analysis. After reconciling coding schema for all gestures, we further disaggregated the data by identifying the type of dialogic context within the instructional period. This yielded three broad emergent contexts within which Ms. Collins produced her gestures. The first one identified was *behavioral/ classroom management*, the context in which Ms. Collins' gestures and speech prompted students to demonstrate the appropriate or expected behaviors as participants in the classroom community. The second emergent context identified was *procedural instructions*, those produced to explain or demonstrate tasks or actions students would be engaging in during the lesson activities. Third, *facilitating discussion* is the context wherein the instructor's speech and gestures were closely related to discussions or direct instruction of the content or conceptual ideas.

Results

Before discussing findings from our comparative analysis, it is important to articulate exactly how we implemented McNeill's (1992, 2005, 2006) framework using several examples of Ms. Collins' instructional gesturing. In order to efficiently associate and analyze Ms. Collins' speech-gesture relationships, we adopted a variation of a commonly used transcription method for investigating nonverbal behavior referred to as "second-line" transcriptions (Lazaraton, 2004, p. 92). In second-line transcriptions, we described gestures and other nonverbal behaviors separately from the verbal channel. We indicate these behaviors by the presence of brackets ([ ]) and place them underneath the verbal channel of the transcription. More specifically, the type of gesture identified (depicted through the gestures' initials, i.e., in brackets such as [i] for iconic and [b] for beat as seen in Table 1) and a description of the gesture is placed directly below specific words or phrases within the speech, or dialogue, during which the gesture was produced. Lastly, the length of the gesture description underlying the text represents the approximate duration of the gesture.

We present the following excerpt, drawn from a discussion on the concept of "movement" to illustrate our argument. Ms. Collins had just finished soliciting examples of movements from her students. In the transcript below, her monologue transitions students to the next activity in which they will further explore movement. Here, Ms. Collins explained what tasks the students would be doing and how they would carry them out, being primarily concerned with providing procedural instructions.

The reader will note that in line 1, Ms. Collins' act of moving her hands appeared to illustrate the word "moving." In this sense, the symbol of the gesture was near to its referent, the idea of "moving," and was thus *iconic* of moving. However, in line 3, in an attempt to quiet the students who continued talking while she presented, Ms. Collins reminded the class to listen. In doing so, she moved her hands, held at either side of her waist, with palms facing down lower, and comes to an abrupt stop with them. This gesture appeared to represent, metaphorically, the lowering of volume among students. *Metaphoric* in nature, the gesture here (line 3) seemed further away from its referent than the representation of moving (line 1) through the concrete action of moving one's hands. In line 3, both the speech and the associated gesture serve a behavioral/classroom-management function as Ms. Collins prompted her students to exhibit a desired behavior.

1. **Ms. Collins: We are going to … start our lesson with moving our bodies**
   [i]moved open-palm hands
   at chest level in
   semi-arcs
2. **Ms. Collins: We are going to do our Halloween dance, you've got to listen**
   [m]open-palm hands
   facing down moving
   downwards
3. **Ms. Collins: Then after our dance, we are going to do movement stations**
   [m]one hand with
   fingers bunched
   with thumb that
   moved in a slight
   arc to center
   of cupped palm of
   other hand

   [i]tented hand apart
   from each other
   started out in
   front of chest
   moved apart and to
   the side and
   moving in a
   circle, briefly
   hovered or
   reached toward the
   direction of each
   table group

5. **Ms. Collins: Christopher … shhh**
   [e]index finger to lip

In line 4, the reader will see the occurrence of two gestures. The first gesture appears to be associated with the word "after." The arching nature of moving one hand concluding with the abrupt stop of this hand against the other palm seemed to indicate a temporal change or the progression from one point to another, however it did not appear to concretely emulate time (itself an abstract concept). Thus, the relatively abstract nature of this gesture is *metaphoric* because it represents an abstract concept. The second gesture in line 4, however, more concretely represents the speech with which it is associated. By tenting her hands and moving in the same pattern that she expected the students to follow from table to table, Ms. Collins employed a *kinetographic* gesture, a representation of the concrete action her students would soon take. The gesture was therefore iconic in nature. Although the nature of the two gestures within this same line of speech appeared to differ, they both served to aid Ms. Collins' explanation of a procedure.

Finally, in line 5, Ms. Collins attempted to silence a child who was talking over her. By placing her index finger over her lips, she utilized a culturally embedded, emblematic gesture commonly understood in the U.S. as an imperative that the recipient cease talking or remain quiet. Ms. Collins provides further evidence of the culturally embedded nature of this gesture with the similarly emblematic sound (i.e., shhhhhh) that she makes to quiet her class. Neither the gesture, nor the sound alone directly conveyed Ms. Collins' request for quiet, but rather their combined symbolism emerged from the larger cultural context. Since Ms. Collins executed the speech and the gesture simultaneously to prompt a desired behavior, we situated this instance in the behavioral/classroom management context.

Exploratory Comparative Analyses

In order to compare the amount of gesturing Ms. Collins employed during science and engineering instruction, we calculated the gesture per minute rate for each lesson (see Table 2). Coding gestural rates allowed us to compare the frequency of certain types of gestures while accounting for differences in the duration of instruction (the science lesson lasted 40 minutes, and the engineering lesson 20 minutes). In doing so, our intent was not to conduct a thorough statistical analysis, but rather to visually represent the gesturing data in a more descriptive manner in line with recommendations from the field of gesturing studies (Gullberg, 2010).

Table 2 demonstrates Ms. Collins' gesture-rates per minute in both science and engineering instruction. Ms. Collins used a total of 51 gestures during the science lesson and 35 gestures during the engineering lesson analyzed for the present article, each of which lasted approximately 40 and 20 minutes, respectively. Despite the relatively short duration of the engineering lesson, Ms. Collins' demonstrated a higher gesturing-rate, which could imply that the engineering content prompted Ms. Collins to gesture more than she did in her science lesson. In addition, the reader will note that Ms. Collins demonstrated visibly higher shares of deictic, metaphoric, emblematic, and hybrid gestures during her engineering instruction. On the other hand, she produced a higher share of iconic gestures during science instruction, with beat gestures remaining about the same in both lessons.

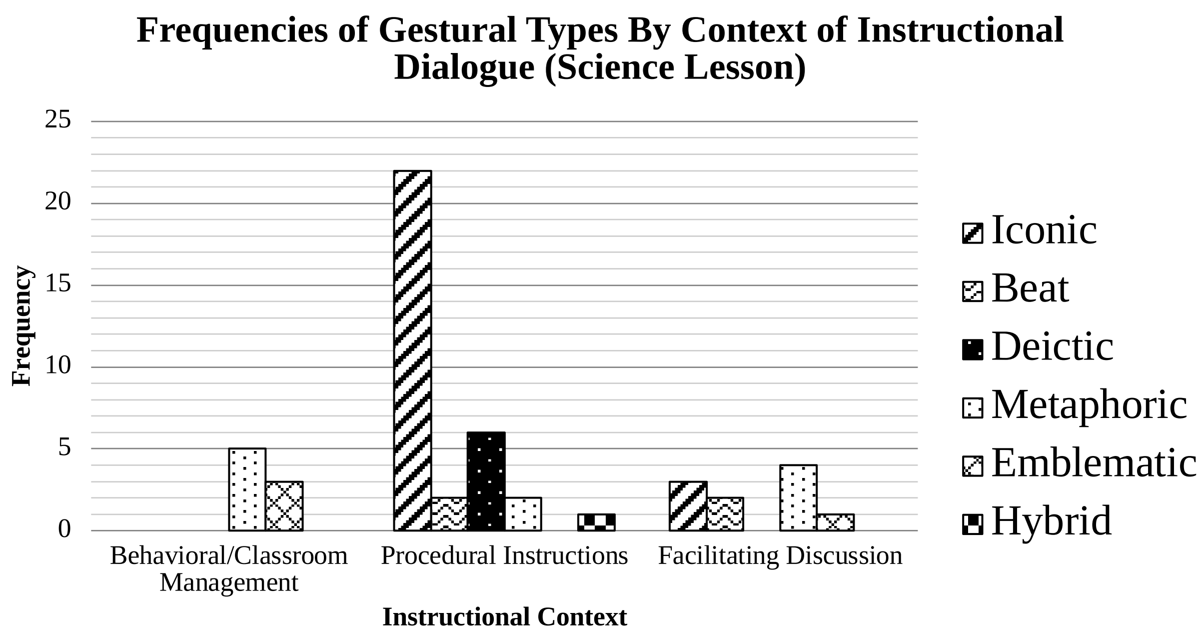
Table 2. *Teacher-Gestures per Minute for both Science Lesson and Engineering Lesson*

Type of Gesture	Science[a] (gestures per minute)	Engineering[b] (gestures per minute)
Iconic	.64	.20
Beat	.10	.10
Deictic	.15	.40
Metaphoric	.28	.40
Emblematic	.10	.37
Hybrid	.03	.30
Total	1.30	1.77

[a]Science lesson lasted approx. 40 minutes with a total of 51 gestures
[b]Engineering lesson lasted approx. 20 minutes with a total of 35 gestures

In an effort to better understand the types of gestures that occurred across both instructional contexts, science and engineering, we compared gesturing frequencies within each instructional dialogue category (behavioral/classroom management, procedural instruction, and facilitating classroom discussions) and across the lessons (see Figure 2).

Figure 2. *Teacher-Gesture Frequencies separated by Context of Instructional Context for Science Lesson*



We include Figure 2 to display the frequency of gestural type by instructional category during science. Ms. Collins produced iconic gesturing most frequently (*n* = 25), especially during procedural instructions (*n* = 22).

We present further evidence of gesturing frequency in the video transcript below. The sequence below lasted close to one minute and 30 seconds, and draws from video data (approximately three minutes long) in which Ms. Collins explained how students would engage with the lesson's stations and their corresponding materials

1. **Okay … so each table is going to have a different something and we**
2. **are going to travel around … I am going to travel around to each**

   [i]tented hand moves in a circle
   along the x,y plane within the
   three-dimensional space

3. **station and we are going to do it … we are going to do it just a few**

   [i]similarly as before, tented
   hand moves in circular
   motions along the x,y plane
   within the three-dimensional
   space

4. **minutes …**

5. **One station is marbles … when you build the marble tower and you**

   [i]moves hands up above each other
   in a pseudo stacking motion

6. **have the marble go in there and you make the marble go down … like**

[i]swirls hand with index finger going down [i]index
finger
going
down

7. the marble goes loopy-loop and all that stuff
[i]index finger pointed out
and down; loops entire hand
in air briefly

8. One of them is with magnets … and you are making the magnet … you
[i]fingers loosely bunched
with palm facing away
from face and moves it
in an s-shape along the
x,z plane in the three-
dimensional space

9. are going to use the magnet roads with one on the top
[i]both hands with fingers loosely bunched [i]one hand with
pointing towards each other fingers loosely
bunched raised
to the top

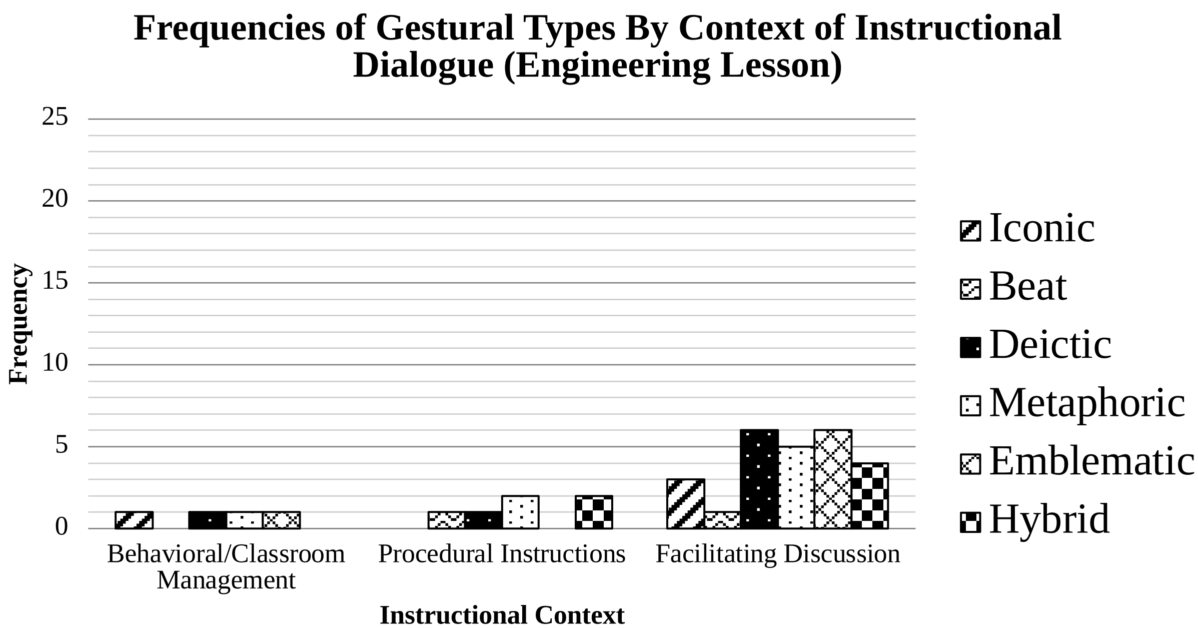
10. one on the bottom, you will need a partner for that one, and you
[i]other hand with fingers
loosely bunched lowered
to the bottom

11. will make the magnet travel along the magnet road
[i]both hands with fingers loosely bunched facing each other
swirling on the x,y plane in the three-dimensional space

Here, Ms. Collins primarily produced iconic gestures as she emulated the actions and movements students would either produce or observe when manipulating materials at each station. For example, in line 10, Ms. Collins described an activity where students would build a marble tower. To symbolize a tower, she stacked her hands, bunching one above the other in a concrete representation of both the action of building (i.e., stacking) and the concept of height, as associated with towers. Similarly, in lines 14-15, Ms. Collins produced more iconic gestures as she demonstrated how students would configure their hands when holding two magnets on either side of a sheet of paper while simultaneously explaining the process verbally. In these sixteen lines (approximately one minute and 30 seconds of instructional time), we observed 11 instances of iconic gesturing. These iconic gestures comprised nearly half of the iconic total during the science lesson, which entailed a substantial exploratory phase that warranted procedural instructions.

The gesturing patterns that emerged in Ms. Collins' instruction differed markedly between engineering and science. Figure 3 compares Ms. Collins' gestural types across the three instructional dialogic contexts during the engineering lesson. Interestingly, iconic gesturing occurred far less frequently during engineering (n = 4) than during science (n = 25) instruction. Furthermore, Figure 3 shows that while most of the gesturing produced in science occurred in the procedural instructional context (n = 32 of 51; 63%), in engineering, the majority occurred when Ms. Collins was facilitating discussion (n = 21 of 35; 60%). Ms. Collins produced a greater variety of gestural types while facilitating discussion; we observed both deictic and emblematic gestures most frequently in this context. The gesturing incidents that occurred while facilitating discussion (*n* = 6 each, deictic and emblematic) are likely associated with the fact that Ms. Collins often manipulated materials and realia (i.e., real-life objects) during the observed discussions, which might have prompted more deictic gestures. In a similar vein, several of the emblematic gestures that occurred in this context mediated communication difficulties between Ms. Collins and her students, where she often used emblematic gestures such as cupping a hand to her ear to prompt students to speak louder in response to a question.

Figure 3. *Teacher-Gesture Frequencies separated by Context of Instructional Context for Engineering Lesson*



We present an example of this variation of gestural types while facilitating discussion during engineering lessons in the excerpt below, derived from a longer segment focused on materials. During this segment, Ms. Collins facilitated a discussion about what things are made of. She named or showed a few objects and asked the students to identify the materials that comprise each object. The following sequence lasted one minute and 30 seconds in real time.

1. **Ms. Collins: What are our pencils made out of?**
   [d]left hand pointing
   towards pencil held by
   right hand
2. **S3: Plastic**
3. **S2: Wood**
4. **Ms. Collins: It's made out of wood, right?**
5. **SN: Yes**
6. **Ms. Collins: What about this part of our scissors?**
   [d]left hand pointing towards
   metal part of scissors
   held by right hand
7. **SN: Metal**

8. **Ms. Collins: Metal! … what about … stop … what about your coffee mugs**
[m]clicks
and points
towards
student
9. **Ms. Collins: that you drink out of?**
[i]cups both hands
over mouth and moves
them forwards and slightly
over her chin
10. **S2: Glass!**
11. **Ms. Collins: They are made out of glass, right?**
[m]from cupped hands, lower
arms and spread them apart
with palms facing up

This segment included at least three different gesture types: deictic, metaphoric, and iconic. In lines 1 and 6, Ms. Collins' use of props such as the pencil and the scissors facilitated the deictic gestures. In line 9, Ms. Collins employed an iconic gesture to refer to and symbolize the action of holding a coffee mug to one's mouth to illustrate her question about what coffee mugs are made of. In line 11, the nature of her gesture was metaphoric—by opening up her palms and raising her hands she represented the rhetorical question, "right?"

While Ms. Collins facilitated discussion in the engineering lesson, we also observed a greater incidence of distinctly hybrid gestures during this time. In the sequence of transcript below, Ms. Collins prompted a discussion about the five senses while discussing how students can make observations about materials. This sequence lasted approximately 45 seconds and produced seven hybrid gestures.

1. **Ms. Collins: We are going to talk about their textures, what they sound**
2. **Ms. Collins: like, what they smell like … we are going to use our five**
3. **Ms. Collins: senses**
4. **SN: Senses**
5. **Ms. Collins: You guys remember what your five senses are? Lea you remember one?**
6. **S1: Taste**

7. **Ms. Collins: Taste … tasting … Jenny?**
[h]points towards
tongue that is sticking
out
8. **S2: Hearing**
9. **Ms. Collins: Hearing … Alex?**
[m]holds both palms
behind both ears
with fingers spread
10. **S3: Seeing**
11. **Ms. Collins: Seeing with your eyeballs … one more … Max?**

[h]takes both index fingers and points to corner of each eye

12. **S4: Hearing**
13. **Ms. Collins: Hearing … seeing … hearing …**

[h]both index fingers pointing/ touching both ears	[h]both index fingers pointing to both eyes	[h]both index fingers pointing/ touching both ears	[h]touches nose with index fingers

14. **SN: Smelling**
15. **Ms. Collins: Smelling … tasting …**

[h]points towards tongue that is sticking out	[m]both hands up with fingers spread and moving

16. **SN: Touching**
17. **Ms. Collins: Touching**

[h]holds both hands up near face, with both palms open and facing students, fingers slightly spread and wiggles fingers

We coded the gestures Ms. Collins produced in lines 6, 10, 12 as hybrid and those in line 14 as deictic-metaphoric combinations. We coded them as deictic because she pointed to various organs on her body, and metaphoric because she referred to students' senses (i.e., sight and hearing) and not the actual organs (i.e., eyes and nose). That is, the organs represented the abstract concepts (senses) they carry out. Line 16 also contains a hybrid gesture that is icono-metaphoric in nature. By wiggling her fingers, Ms. Collins both concretely represented the kinetographic nature associated with moving hands and fingers to demonstrate the act of touching, and referenced the sense, (i.e., feeling a surface). Altogether, these hybrid gestures embodied the dimensional nature of the McNeill's (1992) gestural typologies.

Discussion

Results from our exploratory comparative analyses on the gesture-per-minute rates and across instructional contexts revealed some differences in the types of gesturing produced between science and engineering instruction. Specifically, Ms. Collins implemented a higher rate of iconic gesturing during science. One possible explanation lies in the nature of the science lesson that we observed. The science lesson consisted of an inquiry-based activity during which students explored movement at different classroom stations. As Ms. Collins instructed her students, she used gesturing to model how she expected the students to interact within each station. The instruction itself lent to iconic gesturing as Ms. Collins expected the students to engage in physically oriented procedures, manipulate the materials and move around the classroom.

Likewise, the semantic content of Ms. Collins' procedural explanations for student activities allowed her to represent both the actions and the materials either kinetographic or pictographic. Her gestural symbols were proximal to their referents and provided scaffolds that described the intent of her instructions (Goodwyn et al., 2000). Here, Ms. Collins' gestures eliminated the need for actual tools to demonstrate her ideas, yet they closely mimicked the form of the actions. Symbolic pantomimes such as these have the potential to facilitate English learners' language development in particular, by helping students verbally distance language from its concrete referents.

On the other hand, during her engineering lesson, Ms. Collins enacted higher rates of deictic, metaphoric, emblematic, and hybrid gesturing. Her gesturing happened most frequently when facilitating discussion. Like the science lesson, the nature of the engineering lesson appeared to influence Ms. Collins' gestural production and the contexts in which it occurred. During this lesson, Ms. Collins introduced students to the engineering concept of materials and their properties, engaging with physical objects and gesturing deictically to indicate the materials and pictures in the book she used during the whole-group discussion components of the lesson. Trying to describe properties like surface texture also prompted Ms. Collins to use more metaphoric and hybrid gestures, especially given the presence of realia that served as concrete representations of the materials and properties in discussion.

By employing both metaphoric and hybrid gestures, Ms. Collins created extralinguistic context which could have facilitated her English learners' comprehension. For example, gesturing facilitated not only word denotations, but also connotations and intentions, both direct and implied. Interestingly, however, Ms. Collins employed far fewer iconic gestures in this lesson. Perhaps the heavy materials-use and object-manipulation that characterized this lesson necessarily constrained the production of certain types of gestures, like iconic ones, and promoted the use of others, like deictic gestures.

The concretizing nature of iconic gesturing also becomes especially crucial when accounting for the linguistic needs of English learners. Nicoladis et al. (1999) suggest that iconic gestures could be important in helping young children develop the language necessary to express more complex ideas. Depending on students' English proficiency level, abstract concepts such as "top" and "bottom" could be incomprehensible without Ms. Collins' iconic gesturing. Iconic and metaphoric gesturing also have the potential to serve as cultural mediators during classroom instruction. For example, Ms. Collins instructed her students in the dynamics of "centers." It is possible, if not quite likely, that immigrant English learners might be unfamiliar with "centers", a fairly common practice in which teachers will rotate students through a series of stations, each of which involves a different activity. Centers or stations are fairly common in kindergarten classrooms in the United States. However, by gesturing, Ms. Collins demonstrated the path and the processes she expected the students to follow as they traveled from station to another, as well as the expected interactions for each station.

Overall, Ms. Collins' use of a variety of gesturing forms during both lessons allowed her to supplement her communication methods within each context of instruction (classroom management, procedural, and facilitating discussion) by providing extra-linguistic context as a potential additional support for her students to access linguistic meaning during these science and engineering lessons. Indeed, when asked about the place of language and language pedagogy in math and science instruction during a follow-up interview, Ms. Collins reflected on how gesturing could facilitate communication for students who might otherwise struggle with verbal expressions in English. She commented that

> sometimes the kids don't have the words to tell you, but they can show you. So, there's, you know, the unspoken language of like hand gestures and building and showing you that I can do this and then sometimes they are able to tell me. (Interview 2)

Here, Ms. Collins' comments suggest that she recognizes the important role gesturing can play in helping students negotiate and produce meaning during STEM instruction and learning.

Limitations

As with any analysis pertaining to the complexities of communication and language (and even more so nonverbal, gestural research), this type of study requires a great deal of interpretation on the part of the observers. We are careful to acknowledge the subjective nature of our coding decisions and our interpretations of Ms. Collins' gestures. The very nature of our coding schema applies an interpretation to the representational intent and purpose of each gesture, as well as to every instructional dialogic context. Furthermore, due to constraints of time and access, we were unable to supplement these video observations with additional observations in other subject areas to understand the extent to which Ms. Collins employs gestures as intentional instructional strategies in all content areas. Nevertheless, we strove to make reasonable interpretations, to achieve realistic precision, and to be as consistent as possible during our coding process. We also exerted considerable effort to qualify as many definitions as possible. We attempted to temper our biases through blind coding processes and thorough discussion of any discrepancies before and during the code reconciliation process.

Conclusion

Improving the understanding and implementation of different types of gesturing has the potential to make engineering content (and STEM content more broadly) more accessible to diverse learners, particularly to English learners. Given prior research documenting the importance of early engineering education experiences and the development of engineering concepts, engaging English learners in engineering is particularly important (Ozogul, Miller, & Reisslein, 2017). For example, in their study of children's early engineering conceptions and interests, Ozogul and colleagues (2017) found racial discrepancies in students' accurate understandings of and interests in engineering. Specifically, White students articulated more accurate conceptions of engineering and demonstrated greater proclivities toward it as an occupation, even in early childhood, than their Latinx peers (Ozogul et al., 2017). Considering our findings in light of the prior research, we suggest that all students would benefit from an increase in early engineering exposure, especially English learners. Notably, effective early exposure would require teachers' awareness of the multiple tools, such as gesturing, that might facilitate the engagement of a wide variety of culturally and linguistically diverse learners in engineering. In particular, further exploration of iconic and metaphoric gesturing's potential to make abstract engineering concepts concrete has the potential to inform and produce more equitable practices in early engineering education.

The potential for gesturing as a pedagogical tool becomes increasingly compelling in light of prior research exploring elementary teachers' conceptions of engineering, especially their perceptions of who can successfully participate and why. Sengupta-Irving & Mercado (2017) found that some teachers view the teaching of engineering itself as an equity-driven practice and suggested prompting teachers to interrogate their own beliefs and stereotypes to actively work to counter them. In a similar vein, teachers' examination of their own gesturing habits with respect to alternately English learner or engineering instruction may provide a foundation from which they might begin to intentionally leverage extra-linguistic comprehensible input for diverse language learners.

Future Directions

Although grounded in an elementary engineering context, the present study did not examine students' learning, either outcomes or experiences. Future research will want to examine how extra-linguistic instructional contexts, namely gesturing, may inform English learners' ability to engage with engineering curriculum. In particular, researchers might interview students and examine learning patterns in science, engineering, and even English language development, as they relate to teachers' gesturing patterns. Examination of gesturing in different cognitive tasks warrants would further inform how young learners engage with engineering at the precollege level. Gesturing may be especially salient to early learning processes and outcomes given the complex cognitive processes required of engineering design and problem solving. In addition, future research is necessary to examine how iconic and metaphoric gesturing, in particular, might contribute to the comprehension of the abstract engineering concepts, especially during student-led classroom discussions. While lack of student outcome data precludes us from making inferences in that regard here, future research examining the role of iconic gestures in elementary engineering instruction will inform disciplinary language development research, content-area mastery, and problem-solving capacity.

In short, further inquiry into gesturing at the nexus of language and engineering development is bound to offer important insights regarding elementary engineering curriculum development and design, as well as teacher professional development efforts. These insights will facilitate the incorporation of engineering instruction throughout PreK-12 education. Moreover, these efforts will be vital to make STEM learning more accessible to an increasingly diverse group of learners, facilitating their participation within the STEM community of practice.

In their call for future research, Sengupta-Irving and Mercado (2017) highlight the important potential of engineering in early education, stating:

> Engineering in science could play a transformative role in children's experiences; it could fundamentally rewrite how children see themselves, the purposes of engineering and science learning, and their futures. Thus, what is at stake is not just the sustainability of yet another milestone in national reforms of science education, but the very possibility that doing this well is the greatest investment in our children someday solving the most pressing social and scientific problems of their time. (p. 120)

We take up their call to note the potential of engineering and build on the potential of gesturing in elementary engineering education to contribute to the linguistic and cognitive development of the growing English learner population. In fact, one in ten students in the U.S. is presently EL-identified, and one in five will be EL-identified at some point in time over the course of their K-12 experience (Kieffer & Thompson, 2018). As a community of educators and engineers, it is imperative that we continue exploring ways in which to cultivate the potential for academic success, especially as it relates to STEM participation for this large and growing population.

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