2021

Intersecting Engineering and Literacies: A Review of the Literature on Communicative Literacies in K-12 Engineering Education

Katarina N. Silvestri

State University of New York, Cortland, katarina.silvestri@cortland.edu

Michelle E. Jordan

University of Arizona, michelle.e.jordan@asu.edu

Patricia Paugh

University of Massachusetts Boston, Patricia.Paugh@umb.edu

See next page for additional authors

Follow this and additional works at: <https://docs.lib.purdue.edu/jpeer>

Part of the [Engineering Education Commons](#), and the [Language and Literacy Education Commons](#)

Recommended Citation

Silvestri, K. N., Jordan, M. E., Paugh, P., McVee, M. B., & Schallert, D. L. (2021). Intersecting Engineering and Literacies: A Review of the Literature on Communicative Literacies in K-12 Engineering Education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 11(1), Article 1.

<https://doi.org/10.7771/2157-9288.1250>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

This is an Open Access journal. This means that it uses a funding model that does not charge readers or their institutions for access. Readers may freely read, download, copy, distribute, print, search, or link to the full texts of articles. This journal is covered under the [CC BY-NC-ND license](#).

Intersecting Engineering and Literacies: A Review of the Literature on Communicative Literacies in K-12 Engineering Education

Abstract

Given the increased attention on pre-college engineering education and its disciplinary nature pertaining to language, discourses, and communicative practices, this *state-of-the-art literature review* focused on findings of research articles informed by qualitative and quantitative data to foreground communicative literacies within engineering design teams at the pre-college level. A disciplinary literacies framework was used to interpret and analyze published works in this particular domain. A search, selection, and inclusion process typical for state-of-the-art reviews yielded 33 studies. Constant comparison and open-coding led to clustering studies under five overarching themes in ranked order of frequency of occurrence pertaining to: (a) engineering disciplinary communicative literacies in practice; (b) matters of access with populations underrepresented in engineering; (c) learning STEM content through engineering design; (d) affective responses to uncertainty and risk in engineering design; and (e) evaluating the quality of collaboration. With respect to the themes, we discuss possibilities of using literacy frameworks to deepen theoretical and methodological insights into the study of phenomena related to within-group communicative literacies in K-12 engineering spaces.

Keywords

engineering education, communication, small-group interaction, disciplinary literacies

Document Type

Research Article

Authors

Katarina N. Silvestri, Michelle E. Jordan, Patricia Paugh, Mary B. McVee, and Diane L. Schallert

Journal of Pre-College Engineering Education Research 11:1 (2021) 1–25

Intersecting Engineering and Literacies: A Review of the Literature on Communicative Literacies in K-12 Engineering Education

Katarina N. Silvestri¹, Michelle E. Jordan², Patricia Paugh³, Mary B. McVee⁴, and Diane L. Schallert⁵

¹State University of New York, Cortland

²University of Arizona

³University of Massachusetts Boston

⁴University of Buffalo/SUNY

⁵University of Texas at Austin

Abstract

Given the increased attention on pre-college engineering education and its disciplinary nature pertaining to language, discourses, and communicative practices, this *state-of-the-art literature review* focused on findings of research articles informed by qualitative and quantitative data to foreground communicative literacies within engineering design teams at the pre-college level. A disciplinary literacies framework was used to interpret and analyze published works in this particular domain. A search, selection, and inclusion process typical for state-of-the-art reviews yielded 33 studies. Constant comparison and open-coding led to clustering studies under five overarching themes in ranked order of frequency of occurrence pertaining to: (a) engineering disciplinary communicative literacies in practice; (b) matters of access with populations underrepresented in engineering; (c) learning STEM content through engineering design; (d) affective responses to uncertainty and risk in engineering design; and (e) evaluating the quality of collaboration. With respect to the themes, we discuss possibilities of using literacy frameworks to deepen theoretical and methodological insights into the study of phenomena related to within-group communicative literacies in K-12 engineering spaces.

Keywords: engineering education, communication, small-group interaction, disciplinary literacies

Introduction

The purpose of this literature review is to examine empirical findings from qualitative and quantitative traditions that foreground *within-group communicative literacies* within the discipline of engineering at the pre-college (K-12) level. In this review, we draw attention to the following points: (1) there is a growing recognition and need to attend to language and discourse concerns in K-12 engineering education; (2) with this need, we recognize a concern to review the scope and characteristics of the extant research pertaining to communicative literacies in K-12 engineering design teams; and (3) we offer how communication and literacy frameworks may be useful theoretically and methodologically in current and future research in K-12 engineering education. We are pursuing these points through what Grant and Booth (2009) describe as a *state-of-the-art review*, one that establishes the current state of understanding on a relatively recent development in a field and explores priorities for future research.

In the past decade, educators and educational researchers have increasingly focused on K-12 engineering education. This focus has been evidenced, for instance, by the creation in 2011 of a research journal dedicated to this topic, the *Journal of Pre-College Engineering Education Research*. It was also heralded by two national reports (National Research Council [NRC], 2009, 2012), and by including engineering standards in the Next Generation Science Standards (NGSS Lead States, 2013). These reports argued for greater integration of language and literacy foci within science, technology, engineering, and mathematics (STEM) education from the earliest years of schooling. Concomitantly, apprenticeship into science and engineering practices requires that teachers support oral and written communication for the purposes of doing science and engineering. Interestingly, there have been nuances in expectations across STEM practices. For example, explanations in science that verify discoveries about the natural world differ from engineering discourses where students communicate about design solutions to specific problems. Although reports have outlined the need for disciplinary discourse in classrooms, questions remain about how best to enact necessary instruction (Wright & Domke, 2019).

Relatedly, the NGSS have also inspired a greater focus for inclusion of identity groups historically underrepresented in jobs in STEM (i.e., girls/women, African-Americans, Latinx, English learners, low socioeconomic status), and for preparing students for the influx of engineering careers projected over the next few decades (National Academy of Engineering [NAE], 2004). Given the “language-intensive nature of NGSS science and engineering practices” (Lee et al., 2019, p. 318) coupled with increased focus toward culturally responsive and sustainable disciplinary discourses, a focus on learning and literacy practices of these K-12 students underrepresented in engineering appears warranted (Lee et al., 2013).

Before describing the methods we employed for this state-of-the-art review, we address three initial areas:

1. define literacy,
2. provide a rationale for the study of communicative literacies in K-12 engineering design contexts, and
3. close by describing a framework for disciplinary literacies.

What Is Literacy?

The terms *literacy* and its plural *literacies* have been interpreted differently across different fields of study. The authors of this article have worked in partnerships with engineers, engineering educators, and STEM educators to investigate STEM instruction (Park, Choe, Schallert, & Forbis, 2017; Bowers, Jordan, Evans, Fischer, & Holman, 2019). Although we have collaborated with others to focus on K-12 classrooms and on supporting student identity groups currently underrepresented in STEM careers (e.g., McVee et al., 2017; Paugh et al., 2018), we have positioned ourselves first and foremost as literacy researchers. Because we write from perspectives of literacy scholars, it has been important to consider the network of meanings that literacy researchers index when they use the term *literacy* or *literacies*.

For many researchers and educators, *literacy* has referred primarily to the reading of print text or the writing of print text. By contrast, many *literacy* researchers have defined it as “the process of using reading, writing, and oral language to extract, construct, integrate, and critique meaning through interaction and involvement with multimodal texts in the context of socially situated practices” (Frankel et al., 2016, p. 7). The practices used to make meaning from and produce these texts can be general in nature and useful in all subject areas (e.g., comprehension skills, study skills, notetaking), or they can be thought of as discipline-specific (see Disciplinary Literacies section). Clearly, the term *literacies* has extended beyond the processing and production of written text. We have used the phrase *communicative literacies* to refer to the subset of literacy practices of using oral and written language modalities (i.e., speaking and listening, reading and writing) as well as nonverbal modalities of communication (i.e., gesturing, body positioning, sketching) to convey and make sense of information. As such, literacy and language have been considered to be *multimodal* (Grabin, 2019). When these communicative literacies take place between two or more students working towards a common task or goal, these can be described as *within-group communicative literacies*.

Within-group communicative literacies taking place within group or pair work can foster thinking and language use around the collective solving of a task (Lwin et al., 2012). Some examples of within-group communicative literacies include smaller skills such as turn-taking, trust-building, decision-making, active listening, and conflict management (Frey et al., 2009). These smaller skills help students with larger tasks related to an assignment or project. Communicative literacies can also be considered discipline-specific. In engineering, within-group communicative literacies can include student interactions during the course of teamwork and collaboration on engineering design tasks.

Communicative Literacies in K-12 Engineering Design Contexts

Within-group communicative literacies have been deeply relevant practices in the field of engineering. Although the study of communicative or multimodal literacies has a long history in science education (e.g., Lemke, 1990; Singer et al.,

2008), work attending to children engaged in engineering design processes (EDPs) and communicative literacies has been limited. EDPs, especially those simplified for use with children (e.g., Engineering is Elementary, NASA Design Squad), have involved key phases such as *problem-scoping*, *brainstorming/sharing ideas*, *designing*, *building*, *testing*, *evaluating*, and *sharing solutions* within the context of an engineering design team. Research situated in engineering design contexts has lent itself to our interest in student-led small groups engaged in teamwork enacted through communicative literacies. We have seen this delimitation of our focus on engineering design contexts as not a narrowing of focus but as a legitimate place where *within-group communicative literacies* occur.

This understanding of communicative literacies specific to both science and engineering has been a focus of the NGSS (NGSS Lead States, 2013). Specific to engineering, the NGSS stated that engineering is a language-intensive discipline requiring students to engage in engineering discourse, including that K-12 students collaborate effectively with others on engineering design tasks (NGSS Lead States, 2013). Communicative literacies (i.e., teamwork, collaboration, interpersonal communication) have been expected in engineering and engineering education (Accreditation Board for Engineering and Technology [ABET], 2015; NGSS Lead States, 2013). Additionally, frameworks guiding K-12 engineering curricula have involved elements of working in small groups on design teams, with communication and teamwork as key indicators of quality of K-12 engineering programs (Moore et al., 2014).

Although progress has been made in developing models and curricula that consider literacy- and language-related engineering habits of mind (e.g., Marshall & Berland, 2012; NAE, 2009) such as sharing design ideas and collaborative decision-making, there remains a strong need for empirical research regarding these interpersonal practices inherent to engineering design, particularly in K-12 education (Katehi et al., 2009). These literacy- and language-related engineering habits of mind can be considered discipline-specific practices within the field of engineering. In other words, they are *disciplinary literacies* of engineering.

Furthermore, although policy and standards documents have highlighted the importance of teamwork and discipline-specific communicative practices on engineering teams, studies of college-level engineering education have revealed a need for a pre-college focus on such disciplinary practices. For example, a recent study by Cerato et al. (2011) reported that college-level engineering students were underprepared for working on collaborative teams when compared to individually oriented technical and content-related skills. The increased focus on engineering in the K-12 context as described above has provided opportunities for students to develop engineering communicative literacies prior to entering college. Further, interdisciplinary teams of literacy and STEM researchers who study communication in engineering education settings, both pre-college (e.g., Shanahan et al., 2016) and college (e.g., Moore-Russo et al., 2017), have asserted that students need explicit guidance to engage productively in teams when working on design tasks. Thus, more nuanced research is needed regarding teaching and learning of interpersonal, team-based practices inherent to engineering (Leydens, 2012).

Although there have been syntheses of curricula, research, practices, and/or policies involving engineering education writ large (e.g., Katehi et al., 2009), there does not yet exist a synthesis of data-informed research pertaining to communicative literacies of engineering in pre-college (K-12) contexts. This is likely due to both the relatively emergent nature of the field and, we hypothesize, its interdisciplinary nature. There are multiple, seemingly disparate stakeholders invested in this particular intersection of engineering and communicative literacies, including engineering educators, literacy educators, science educators, STEM policy and curriculum developers, and scholars focused on discourse and group dynamics. As such, a clearer picture of the phenomena of communicative literacies in pre-college engineering design teams requires a concentrated study of literature across these domains.

Yet, communicative literacies tend to be defined using various terminology within the domains of engineering (e.g., *collaboration*, *communication skills*, *soft skills*, *teamwork*), literacy studies (e.g., *discourse*, *language*, *small-group/peer interaction*, *talk*), and guiding documents that link engineering with science learning, such as the NGSS (NGSS Lead States, 2013) (e.g., *science discourse*, *language-intensive*, *argumentation*). Moreover, the proliferating vocabulary related to pre-college engineering communicative literacies is likely due to the complexity of the embodied experience of engineering and due to the intersection of communication and embodied practice. Consider, for example, how EDPs require multiple dimensions of collaboration and communication. Engineering practices are intertwined with communicative practices for thinking and reflective decision-making within teams, as well as with stakeholders outside a team. With respect to the discipline of engineering, such reflective conversations involve not only talk but multimodal tools, material resources, artifacts, and inscriptions (Cunningham & Kelly, 2017; Schön, 1992).

Disciplinary Literacies

The framework guiding our work, that of *disciplinary literacies*, has been rooted in sociocultural perspectives that portray practices as situated in a constitutive historical and current context (Bazerman, 1985; Ho, 2011; Holmes & Woodhams, 2013; Moje, 2007; Roozen, 2010). Pleasants and Olson (2018) observed that engineering requires specific sets of practices,

capacities, and knowledge bases (i.e., *nature of engineering*) related to, and yet distinct from, science and technology. These aforementioned knowledge bases have included the necessity of working effectively with others in teams. Reading and writing texts (i.e., functional literacies) have typically been associated with schooling, but disciplinary literacies also include other within-group communication practices (e.g., listening, collaborative thinking, gesturing, inscribing, handling objects) that have potential roles specific to engineering.

In K-12 education, at both the elementary level (Brock et al., 2014) and secondary level (Moje, 2008), scholars and teachers using a disciplinary literacies framework have sought to understand the types of literacy practices specific to particular domains in K-12 education, such as English language arts (Rainey & Moje, 2012), history (Manderino, 2012), mathematics (Hillman, 2014), science (Cervetti et al., 2012), and STEM in general (Hart & Bennett, 2013). Fang (2012, p. 20) noted that disciplinary literacies require “both deep knowledge of disciplinary content and keen understanding of disciplinary ways of making meaning... simultaneous engagement with disciplinary content (e.g., core concepts, big ideas, key relationships) and disciplinary habits of mind (e.g., reading–writing, viewing–representing, listening–speaking, thinking–reasoning, and problem-solving...)” (see also Flury-Kashmanian, 2016; Giroux & Moje, 2017). When considering within-group communication practices, particularly in school contexts, linguistic modes of communication (e.g., reading, writing, listening, speaking) are highly valued. However, a disciplinary literacies approach includes all modalities, such as object-handling, moving one’s body, drawing, and modeling (e.g., body proxemics, gaze, touch) (Lemke, 1990; Roth, 2001; Smagorinsky et al., 2005). These communicative modalities intersect with engineering habits of mind such as adapting, problem-finding, creative problem-solving, visualizing, and systems thinking (Royal Academy of Engineering, 2014; Yore et al., 2003).

Taken together, enacting the literacy practices described above in learning environments has been akin to taking up or “trying on” the identity and discursive practices of a person working in that particular discipline, that is, reading, writing, designing, thinking like an engineer, historian, scientist, and/or writer (Cervetti & Pearson, 2012). As a theoretical framework, disciplinary literacies have focused attention at the intersection of the discipline-specific content, literacy practices for the discipline, and the larger identities and discourses embedded in the knowledge base and practices of the profession (McVee et al., 2017).

Although there has been an established tradition of studies in K-12 education pertaining to science identity (Kelly et al., 2017), there are still comparatively few studies specific to K-12 engineering and identity. Some studies in engineering have explored how children perceive engineers and engineering, for example by using the Draw an Engineer Test (Capobianco et al., 2011). Additional work related to identity has focused on a measure of engineering identity development, such as the Engineering Identity Development Scale (EIDS) (Capobianco et al., 2012). Engineering interventions using the EIDS have connected an increase on the engineering careers subscale with a higher engineering career identity (Yoon et al., 2014). Notably, in relation to the NGSS focus on early development of STEM identities for underrepresented groups, the literacy-related practices of Latinx youth and their connection to socially situated identities related to engineering knowledge have been studied. Findings have underscored the value of active linkages of adolescents’ funds of knowledge coming from their communities, families, and recreational activities (Wilson-Lopez et al., 2016) and of inclusion of critical literacies in the context of engineering design with adolescents in secondary schools (Wilson-Lopez et al., 2017).

As discussed previously, engineering is both an interdisciplinary field, inclusive of science, math, and technical elements, as well as a domain in itself, with its own ways of knowing, thinking, doing, and languaging. Thus, complexity necessarily exists in engineering disciplinary literacies (Wright & Domke, 2019), particularly from a communicative standpoint when engineering design is enacted in team-based and/or small-group contexts (Dym et al., 2005; Leydens, 2012; Moore et al., 2014). The importance of interactional competencies has been stressed in pre-college engineering education policy documents, standards, and curricula. However, the research pertaining to the teaching and learning of communicative literacies in K-12 contexts is distributed across various publication outlets geared to different disciplinary groups. It is our purpose here to provide a current scope of empirical research conducted on disciplinary communicative literacies enacted within K-12 engineering design teams, inclusive of empirical research at interdisciplinary crossroads of both engineering and literacy education.

Research Methods

Pre-college engineering education has emerged as a field over the past two decades. Contributing to the knowledge base in this area have been two literature reviews. Diaz and Cox (2012) reviewed 50 research papers within a U.S. context, followed by Hynes and colleagues (2017) who updated and expanded this review across an international context. The focus of these reviews was to frame existing research in order to inform and improve the “perception, knowledge, and abilities” of both teachers and students (Hynes et al., 2017, p. 1). The intention of this current review on communicative literacies in K-12 engineering is to develop a deeper focus on disciplinary communication, one dimension integral to learning across the

design cycle. We also intend to highlight the intersection of the two fields of engineering education and disciplinary literacies. We chose a state-of-the-art approach to this literature review guided by Grant and Booth's (2009) typology of 14 approaches to reviews. This is because our interest is in a body of work that, relative to other domains of engineering education (e.g., undergraduate and graduate engineering education), is only recently emerging.

Following recommendations for a state-of-the-art review, our approach to identifying and analyzing the literature involved identification of search terms and initial database searches, identification of journals by hand search, and selection of articles for inclusion. A preliminary database search was conducted through Education Source, filtering for peer-reviewed journal articles within the past 10 years (2010–2019). To be included in this state-of-the-art review, the article needed to meet the following criteria: (1) include empirical research, (2) involve participants identified as “pre-college” (K-12) students, (3) involve research questions and findings focusing on small-group interactional data, and (4) focus on K-12 students engaged in engineering design activities. Table 1 reflects terms used during this initial search.

We selected this diverse set of terms to conduct our search, after initial explorations of the literature confirmed our sense that engineering standards (e.g., NGSS), accreditation documents (e.g., ABET), and research did not identify a single term that reliably captured within-group interaction of groups engaged in EDPs. The challenge to integrate this interdisciplinary literature was further exacerbated by the fact that researchers and practitioners were reporting on engineering design work without using the term *engineering* (Rodriguez, 2015). Given that the focus of this review was on communicative disciplinary literacies of *engineering*, we purposefully limited our search to studies specifically identified as conducted in engineering design contexts. Because engineering design contexts have been those where students engage in EDPs, engineering design contexts offer many opportunities for within-group talk. Figure 1 represents our entire search, selection, and inclusion process.

We cross-referenced three sets of search terms in Education Source to review the literature on communicative literacies in pre-college engineering: (a) engineering education, engineering, AND (b) collaborat*, communicat*, interactional, interpersonal, shared regulation, soft skills, teamwork AND (c) elementary school, middle school, high school, secondary school, pre-college. Education Source served as a way to search through education journals writ large, because our focus was on engineering education specifically. We subsequently cross-referenced the terms disciplinary literac* AND engineering. Finally, after noting that multiple studies foregrounded argumentation occurring in small groups in engineering design contexts, we added the term argument* to the three sets of search terms listed above. Based on the above criteria, the first two authors worked individually to review titles and abstracts that surfaced from each search combination, selecting only studies that met the four delimiting criteria listed above when research questions and findings were reviewed. An article was included in the review only after discussion between the first and second authors. Through this process, 13 studies were identified in the initial database search.

As it is common practice in engineering to publish peer-reviewed conference proceedings as full papers, we searched the proceedings of the American Society for Engineering Education (ASEE). We specifically selected the ASEE Annual Conference and Exposition because the organization represents itself as the “only conference dedicated to all disciplines of engineering education” (ASEE, 2018), and because it is recognized as a premier conference for publishing engineering education research pertaining to pre-college students. As such, we replicated our database search while also including the term “fundamental,” which identifies empirical research in ASEE proceedings as well as filtering for the division of *K-12 & Pre-College Engineering* or *Pre-College Engineering Education Division*, as different terms are used to identify this division between the years 2010 and 2019. Notably, there was no difference in number of results when searching for the terms “engineering” and “engineering education” in conjunction with the communicative literacies terms, so totals were only counted once. We also did not distinguish between different grade

Table 1
Literature review search terms in initial search.

Term combinations for initial database				
engineering education	AND	collaborat* communicat* interaction*	AND	elementary school middle school high school secondary school pre-college
engineering		interpersonal shared regulation soft skills teamwork argument*		
disciplinary literac*	AND	engineering

Figure 1. Representation of the full search, selection, and inclusion process.

levels, as we were able to search specifically for “pre-college” studies in the ASEE database. Based on those criteria, eight studies published as conference proceedings were included in this review from the ASEE Annual Conference and Exposition search.

Finally, we performed a hand search through ten years of journals that either (a) contained articles already identified in the initial round of searches; or (b) were related to STEM education, and/or literacies, and that publish research on pre-college/K-12. We included science and STEM education journals because even though engineering may not be the focus of these journals, engineering education research has been published in these outlets (e.g., *Journal of Research in Science Teaching*; *International Journal of Science Education*). We also focused specifically on engineering education journals (e.g., *Journal of Pre-College Engineering Education Research*, *Journal of Engineering Education*, *Journal of Professional Issues in Engineering Education*, etc.). A total of 16 journals were included in this hand search. Results from reviewing titles and abstracts in the hand search of these journals yielded 20 possible studies that fit our state-of-the-art review criteria above. After review and discussion by the first two authors and a search of the journals listed in Table 2, only 12 research articles met our criteria.

Thus, within these searches, a total of 25 journal articles and 8 conference proceedings were located that fit our criteria. (Note: these studies are marked with an asterisk in the reference list.) Although a few other studies promoted the use of communicative literacies in engineering design settings (e.g., Bakar et al., 2013), these were eliminated when their findings were not informed by data reflecting within-group interaction.

Results

Having identified 33 studies of within-group communicative literacies in K-12 engineering design contexts, we examined them for characteristics related to purpose, research questions, theoretical and methodological frameworks, participants, findings, and conclusions. Using inductive procedures of reading and noting patterns over multiple rounds of open coding, we arrived at five overarching themes, with several comprising two or more subthemes. Table 3 represents the 33 research articles with respect to their theoretical framework, study design, participants, data sources and analysis, as well as the

Table 2

Literature review hand search journals by subject area.

Journals by subject area and resultant articles (seven total)		
Subject	Journal title	Articles found
Education (multi-subject)	<i>Journal of the Learning Sciences</i> <i>Learning and Individual Differences</i> <i>Theory into Practice</i>	
Engineering education	<i>International Journal of Engineering Education</i> <i>Journal of Engineering Education</i> <i>Journal of Pre-College Engineering Education Research (J-PEER)</i> <i>Engineering Studies</i> <i>Journal of Professional Issues in Engineering Education</i> <i>Advances in Engineering Education</i> <i>IEEE Transactions on Education</i>	<ul style="list-style-type: none"> • Hudson et al. (2013) • Guzey & Aranda (2017) • Watkins et al. (2014) • Valtorta & Berland (2015)
Science/STEM education ^a	<i>Journal of Research in Science Teaching</i> <i>International Journal of Science Education</i> <i>School Science and Mathematics</i> <i>Science and Children</i> <i>Science Education</i> <i>Journal of STEM Education</i> <i>International Journal of Education in Mathematics</i> <i>Science and Technology</i>	<ul style="list-style-type: none"> • Hertel et al. (2017) • Pattison et al. (2018) • Jung & McFadden (2018) • Mathis et al. (2018) • Wright et al. (2018)
Literacies education	<i>Journal of Literacy Research</i> <i>Journal of Adolescent & Adult Literacy</i> <i>The Reading Teacher</i> <i>Reading Research Quarterly</i> <i>Literacy Research: Theory, Method, and Practice</i> <i>National Reading Conference Yearbook</i> <i>Communication Education</i> <i>Linguistics and Education</i> <i>Learning, Culture and Social Interaction</i>	<ul style="list-style-type: none"> • Paugh et al. (2018) • Shanahan et al. (2016) • Jordan (2010)

^aWe have separated the engineering education journals from the science/STEM education journals because the engineering journals are specifically focused on engineering education (i.e., engineering the main part of the journal title), whereas the science/STEM education category of journals are more broadly related to teaching science, technology, and mathematics.

themes they address. In ranked order, from those containing the most to the least number of studies, these themes are phrased as questions we asked of the literature: (a) What communicative literacies are central to engineering? (COMM); (b) How does the literature inform issues of access for identity groups underrepresented in engineering? (ACCESS); (c) How do K-12 students learn STEM content through engineering design? (APPLIED); (d) What roles do affective responses to uncertainty and risk play in engineering design? (AFFECT); and (e) How is collaboration quality evaluated in engineering design? (EVAL). Note that eight studies fell into multiple theme categories. In the sections below, we discuss literature related to each of the five themes by first describing the theme generally, providing brief summaries of key findings, and synthesizing across the findings of studies within each section.

Engineering Disciplinary Communicative Literacies

The first theme names and describes the communicative literacies that have been integral to engineering disciplinary practices in the field (Dannels et al., 2003; Darling & Dannels, 2003; Gorman, 2010; Kedrowicz & Taylor, 2013). This theme was represented by 17 out of 33 articles, and included (a) communicating using multiliteracies, multimodal, and digital means; (b) negotiating through consensus-building, decision-making, and evidence-based reasoning; (c) publicly critiquing; and (d) using the EDP as an organizing principle for engineering disciplinary literacies. The studies foregrounded one or more of these elements of engineering communicative practices on pre-college design teams.

Table 3
Articles addressing K-12 communicative literacies in engineering design activities.

Reference ^a	Framework	Study design	Participants	Primary data sources	Theme
Guzey & Aranda (2017) ¹ Hertel et al. (2017) ²	Situated learning Epistemic practices of engineering	Exploratory case study Educational ethnography, discourse analysis	<i>n</i> = 158th <i>n</i> = 12, 3rd–5th	*AV recordings (small/whole grp) *AV tscrips * field notes *artifacts	APPLIED COMM
Hudson et al. (2013) ¹	Psychol., adolescent development, social constructivism	3-yr ethnography	<i>n</i> = 2 8th girls in mixed-gen. grp	*AV tscrips * field notes *artifacts	ACCESS
Jordan (2010) ³	Psychol. uncertainty; multimodal literacy	Qualitative interpretive	8 5th-gr. classes, 4 grps, 1 class	*AV tscrips	COMM, AFFECT
Jordan (2014) ¹	Engineering as social (comm.) practice	Qualitative discourse analysis	24, 6 grps, 1 class	*AV tscrips	COMM
Jordan (2015) ⁴	Uncertainty management	Case study naturalistic inq.	<i>n</i> = 24 5th, 6 grps	*AV tscrips interviews	AFFECT
Jordan & Babrow (2013) ³	Problematic integration theory, uncert. man.	Qualitative cross-case analysis	<i>n</i> = 12 5th, 3 grps	*AV tscrips	EVAL., AFFECT
Jordan & DeLaRosa (2017) ¹	Engineering as social practice	Design-based research	4 8th-gr. classes	*AV tscrips	EVAL
Jordan & McDaniel (2014) ⁴	Collab prob-solv., uncertainty management	Case study	<i>n</i> = 24 5th, 2 projects	*AV tscrips	AFFECT
Jung & McFadden (2018) ³	Sociocultural theory, epistemic practices, accountable talk	Ethnographic microanalysis	<i>n</i> = 8 5th, 2 grps	*AV recordings *field notes *artifacts	COMM
King & English (2017) ²	Situated cognition; sociocultural theory	Longitudinal case study	<i>n</i> = 24, 8 grps, 4 classes	*AV recordings *artifacts *field notes	APPLIED
Mathis et al. (2016) ¹	STEM integration, Toulmin's argumentation	Exploratory case study	<i>n</i> = 4 7th-gr., 1 grp	*AV tscrips *artifacts	COMM
Mathis et al. (2018) ²	STEM integration	Exploratory case study	<i>n</i> = 4 7th-gr., 1 grp	*AV tscrips *artifacts	COMM, APPLIED
Maxey & Hynes (2018) ¹	Expectation states theory	Case study	<i>n</i> = 24 6th–8th, 8 grps	*AV recordings interviews	ACCESS
McVee et al. (2017) ⁴	Multimodal comm., disciplinary literacies, productive comm.	From larger study: design-based research	<i>n</i> = 3 4th EL female	*AV tscrips *field notes	COMM, ACCESS
Menekse et al. (2017) ¹	PBL 21st century skills	Correlational design	<i>n</i> = 366, 61 K-8 grps	*observation task protocol	EVAL

Table 3
(Continued)

Reference ^a	Framework	Study design	Participants	Primary data sources	Theme
Paugh et al. (2018) ³	Sociocultural frameworks, social semiotic theory	Case study	<i>n</i> = 1 4th EL girl in a grp	*AV tscrips *work samples	ACCESS
Pattison et al. (2018) ²	Identity-frame model	Grounded theory Case study	6 girls (ages 9–11)	*AV recordings, *interviews *reflection	ACCESS
Rynearson et al. (2017) ²	Toulmin's argumentation model	Case study with document analysis	<i>n</i> = 32 Kdgs., 3 classrooms	*AV tscrips *artifacts	COMM
Schmittka & Schmittka (2016) ¹	Gender paradigm of "analogy," cultural difference approach	Exploratory case study; discourse analysis	<i>n</i> = 16 6th–7th, 4 grps	*AV tscrips *pre-/post-tests	ACCESS
Shanahan et al. (2016) ³	Disciplinary literacies, multimodal comm.	Conceptual, illustrative data	<i>n</i> = 12 3rd, 4 teachers	informed by: *AV tscrips *field notes	COMM
Shanahan et al. (2018) ³	Disciplinary literacies, productive comm., multimodal comm.	Conceptual article with illustrative data	1 engin. afterschool club, multiple EDPs	informed by: *AV tscrips *field notes	COMM, ACCESS
Siverling et al. (2019) ²	STEM integration framework; Toulmin's argument. model	Naturalistic inquiry	7 focal grps in 7 classes	*AV tscrips	APPLIED
Siverling et al. (2017) ¹	Toulmin's argument. model	Naturalistic case study	<i>n</i> = 4 7th 1 grp	*AV transcripts	COMM, APPLIED
Valtorta & Berland (2015) ¹	STEM integration	Discourse analysis	HS engin. class, 2 pairs	*AV recordings	APPLIED
Watkins et al. (2014) ¹	Conceptual article; illustrative examples	Qualitative	2 4th gr. classes, 1 teacher	AV recordings	COMM
Wendell & Andrews (2017) ¹	Situated learning, disciplinary literacies, design thinking	Case study micro-ethnographic methods	2 5th-gr. classes, 1 teacher	*AV recordings *artifacts	COMM
Wendell et al. (2015) ¹	Reflective decision making, intertextuality	Qualitative case study	4 classes, 2nd–5th gr., 2 grps	*AV recordings *artifacts	COMM
Wendell et al. (2017) ¹	Reflective decision making, engineering as social practice	Qualitative case study	4 classes, 2nd–3rd-gr.	*AV tscrips *artifacts	COMM
Wendell et al. (2019) ²	Situated learning, epistemic strategies	Interpretive case study	<i>n</i> = 44 4th–5th, 2 classes	*AV transcripts *artifacts	COMM
Wilson et al. (2014) ³	Disciplinary literacies, literacy events (health)	Comparative case study	2 grps of 17-year-old students	*AV recordings *interviews *artifacts	COMM, EVAL
Wright et al. (2018) ²	PVEST, reflective decision making, risk management	Case study	<i>n</i> = 3 5th, 2 classes; 2 grps	*AV tscrips *interviews	ACCESS, AFFECT
Yuen et al. (2014) ⁴	Collaborative learning, group dynamics	Causal-comparative design	<i>n</i> = 70 3rd–8th, 18 grps	*observational protocol	EVAL

^aSuperscript notation references the type of journal in which the article was published: (1) engineering education, (2) science education, (3) literacy education, and (4) general education (multiple subjects).

Communicating Using Multiliteracies, Multimodality, and Digital Means

In practice, engineers do not communicate through linguistic modalities alone but instead rely on drawings and inscriptions, demonstrations and gesture, materials, and various other modalities when conveying meanings (e.g., Geisler & Lewis, 2000; Henderson, 1991; Johri et al., 2013). Similarly, engineers use various tools to document and share ideas, including digital applications using multiple modes (e.g., images, animations, audio, print text, color, etc.) (e.g., Aurigemma et al., 2013; Barr et al., 2002; Martin & Gaffney, 2016; Sorby, 2009). We identified six publications in which researchers attended to how young students learn to communicate multimodally.

Three studies explored multimodal communicative literacy practices in elementary engineering design teams, using multiliteracies, social semiotics, and multimodal perspectives as frameworks. Jordan (2010) exemplified the numerous multimodal literacy practices (e.g., collaboratively building conceptual vocabulary from material attributes like color or size; inscribing a design in both two- and three-dimensional media) that fifth-grade students enacted to convey understandings throughout engineering projects. Here, Jordan argued that engineering projects provide ample opportunities for students to engage in multimodal literacies specific to communications within their design teams (“literacy writ small”) and pertaining to the larger discourse of engineering (“literacy writ large,” p. 271; see also, Jordan, 2014). Similarly, Shanahan and colleagues (2016) conceptualized the disciplinary communicative practices of engineering in their model of *productive communication* that included discourse across semiotic systems (e.g., gesture, gaze, proxemics) while also emphasizing “effective and respectful communicative modes” (p. 410). Using this same multimodal model, McVee et al. (2017) highlighted instances of English language learners using a confluence of modalities to communicate their design ideas, debate, and reach consensus on solutions while engaged in the EDP in a co-ed afterschool club. By so doing, McVee and colleagues highlighted that productive communication in engineering does not necessarily foreground linguistic modalities.

The literature has also highlighted how multimodal communicative literacy practices take place through notebooking with digital and nondigital tools. Shanahan et al. (2018) described *digital engineering design team journals* as a way teams leveraged tablets to capture, edit, and share their thinking about design ideas using modalities such as images, sketches, video, movement, and voice. The authors emphasized that this journaling was particularly helpful for English learners because it provided multiple ways to express ideas successfully beyond linguistic modalities. Wendell and Andrews (2017) described *digital engineering notebook cards* that provided a structure for documenting design elements and scaffolding conversation about the EDP for culturally and linguistically diverse students. Similarly, Hertel et al. (2017) studied how engineering notebooks with prompts from the *Engineering is Elementary* curriculum influenced ways of taking up epistemic practices of engineering in design teams (e.g., providing evidence to support their argument for a particular design idea, constructing explanations, and coming to consensus). Importantly, and aligned with a sign systems framework, notebooks seemed to provide students with a “visual reference for development of explanations” (p. 1211).

Thus, the state-of-the-art in this area pointed to researchers attending to the power of multiple modes of communication, of ways students can be encouraged to interact with each other beyond linguistic means, and of the beneficial consequences of such practices for inclusion of English learners in STEM activities. We also noted a theoretical confluence among most of the studies in this section: nearly all foregrounded the theoretical frameworks of multiliteracies and/or of social semiotics on multimodality.

Negotiating Through Consensus Building, Decision-making, and Evidence-based Reasoning

Eight studies in this review focused on how students in design teams come to negotiate, (dis)agree about, and decide on actions throughout the EDP. Not surprisingly, because of their interest in the negotiation processes of design teams, the following studies relied on the methodological strengths of discourse analysis.

Jung and McFadden (2018) specifically focused on the justification of design choices of teams working to create a prototype for a survival suit. The authors found that teams tended to rely on verbal legitimization of their design ideas within their groups using personal authority (i.e., relying on one’s own experience or knowledge) as well as supporting design choices by referring to data (i.e., data tables generated by the students’ testing of different materials), the latter being the practice particularly supported by the teacher. Echoing the NRC’s (2012) recommendations, Jung and McFadden argued that the flexible use of both kinds of legitimization is part of an engineer’s disciplinary practices.

In two studies, Wendell et al. (2015, 2017) delved into the collaborative, communicative practice of *reflective decision-making*. These authors explored how students drew on diverse personal and cultural semiotic resources to respond to the disciplinary literacy demands of engineering planning through linguistic (i.e., speech, writing) and nonlinguistic modalities (i.e., sketching, gesture, materials usage). The extant literature revealed six elements of reflective decision-making in practicing engineers, which were used to analyze the teams’ negotiation processes: (a) articulating multiple solutions, (b)

evaluating pros and cons, (c) intentionally selecting a solution, (d) retelling performance of a solution, (e) analyzing solutions according to evidence, and (f) purposefully choosing improvements. Moment-by-moment discourse analysis of team interactions revealed instances of reflective decision-making interspersed with moments of less productive interactions. Some less productive interactions and within-group tensions were brought about by socially and academically motivated norms of competition, failing to notice design failures, and struggling to find a common vocabulary to discuss designs. As for productive instances of reflective decision-making, there were larger practices at play, such as reflecting on prior design decisions, gathering and analyzing additional information, and being deliberate about taking next steps as a team.

Hertel and colleagues (2017) also focused on decision-making and consensus-building as epistemic, disciplinary practices of engineering supported by notebook use. Specifically, the notebook and its prompts helped guide students in within-group conversations in explaining the rationale behind their decision-making, as well as providing evidence as they advocated for their own design ideas before having to come to consensus on one design. The authors additionally brought attention to the relationship of these epistemic, disciplinary practices and the importance of larger classroom discourse norms that promote communication within teams.

Wendell et al. (2019) traced the development of students' design knowledge through discourse analysis of spoken, written, visual, and digitally created classroom texts. The authors focused on how knowledge was represented across sequences of prototypes rather than singular reflection on the current or final set of prototypes. Findings outlined how students generated knowledge supported by three "epistemic tools": digital design notebooks, classroom "design talks," and poster creation. Building on Hertel et al. (2017), Wendell et al. (2019) emphasized the power of spoken discourse in "design talks," digital notebooking, and multimodal poster creation for students' decision-making across time.

Embedded within the practice of reflective decision-making is *argumentation* (i.e., discussing and evaluating the pros and cons of a statement, proposition, or position). Argumentation has long been a cornerstone of science inquiry learning, where it is used to support one's claim about a hypothesis. In engineering, argumentation has been related to supporting design decisions, developing multiple solutions, and coming to consensus about a given problem in the context of a design team. Through our literature review, we found that discursive actions related to argumentation in engineering are termed *evidence-based reasoning* and were represented in three studies.

Mathis and colleagues (2016) discovered that evidence-based reasoning occurred during the initial planning, implementation, testing, and evaluation phases of the EDP. These authors found that students' evidence-based reasoning tended to be implemented by coming to consensus on design decisions, especially while advancing one's idea, requesting and providing clarification, and encountering misunderstandings or misconceptions. Siverling et al. (2017) built upon the above work with a more nuanced analysis of interactional episodes, highlighting and illustrating "categories of situations" that prompted seventh-grade students' evidence-based reasoning (e.g., responding to teammates' queries, challenging or defending design ideas, supporting another's design idea by providing more evidence).

In a similar vein, Rynearson and colleagues (2017) sought to identify and describe moments when kindergarten students engaged in evidence-based reasoning during a STEM and literacy curriculum focused on engineering design. Although students sometimes spontaneously engaged in evidence-based reasoning with their peers, they tended to make basic claims and rarely followed up with evidence or backing. However, kindergarteners *did* successfully and consistently provide evidence for claims when prompted by a teacher to do so.

In sum, the state-of-the-art in this area pointed to a strong interest in how students negotiate with each other, come to consensus about engineering design decisions, and use evidence-based reasoning. The data came from discourse analysis of the talk taking place in small group discussions, occasionally relying on Toulmin's argumentation pattern. Several of the studies described the use of graphic and notebook-supported discourse prompts, thereby extending an interest in small group discourse to include nonverbal means of communication. We also noted that several of the above studies connected their analyses to features of discourse practices typical for engineers, thereby making explicit the interest researchers have in discipline-specific discourse, specifically engineering as a discipline.

Publicly Critiquing

Another engineering disciplinary communicative practice commonly found on design teams is *public design critique*, the goal of which is to improve future iterations of a given design or prototype. In the single study identified under this subtheme, Jordan (2014) sought to uncover how public critique of designs shaped ongoing within-group interaction on one robotics design project. Two focal teams were purposefully selected based on the kind of feedback received from their teacher and peers. The design team receiving negative feedback became more task-oriented with an increase of design ideas shared, having fewer social-relational (i.e., unrelated to task) interactions than prior to the feedback. The design team receiving positive feedback had an equal amount of design-related interactions both before and after critique. After

receiving feedback of any kind, both teams were enthusiastic about making improvements on their solution to their respective design problems.

Using the EDP as Organizing Principle for Communicative Literacies in Practice

Five of the reviewed studies organized analysis of design teams' discipline-specific literacy practices by explicitly linking them with specific phases of the EDP (e.g., define problems, generate ideas, communicate solutions). Watkins and colleagues (2014) argued that analysis of youths' problem scoping behavior should take account of the complexity with which students consider multiple criteria, weigh decisions, and pursue design solutions. To support this claim, these authors illustrated how fourth-graders' collaborative discourse during open design projects reflected aspects of expert engineering problem-scoping practice (e.g., considering multiple perspectives while exploring the problem space, scoping sub-problems, balancing and prioritizing priorities, negotiating different perspectives).

The four other studies that used the EDP to organize their findings also fell into other themes of ours. In both Mathis et al., (2016) and Siverling et al., (2017) used coding schemes that identified different phases of the EDP as well as markers for evidence-based reasoning. Thus, evidence-based reasoning was located across multiple phases of the EDP. Mathis and colleagues (2018) (also see section *Learning STEM Content Engineering Design*), also focused on students' reasoning during ideation phases of the EDP, highlighting how discourse related to math and science concepts during the problem scoping phase was used to generate solutions. Wilson et al. (2014) compared high school groups' literacy practices during engagement in the EDP. Findings were that groups that collaborated more effectively and more frequently across the EDP had more optimal design thinking around the problem when compared to groups exhibiting less effective collaboration (see also *Evaluating Quality of Collaboration*).

Matters of Access with Identity Groups Underrepresented in Engineering

A total of eight studies in this review questioned dominant engineering discourses from one perspective to another. Part of expanding the engineering pipeline to be more inclusive of historically underrepresented identity groups meant attending to matters of access to engineering experiences for these students. The organization of this section refers to studies about students in these identity groups that met our review criteria, including students attending schools with urban characteristics (Wright et al., 2018), students learning English as a new language in primarily English-speaking countries (McVee et al., 2017; Paugh et al., 2018; Shanahan et al., 2018), and students from families of low socioeconomic status (Maxey & Hines, 2018). Additionally, because engineering remains a highly gendered field comprised mostly of men, researchers have been interested in studying interactional processes in design teams from lenses of culturally situated gender norms (Hudson et al., 2013; Pattison et al., 2018; Schnittka & Schnittka, 2016).

Students in Schools with Urban Characteristics

Wright and colleagues' (2018) study of how elementary students in two urban schools developed engineering identities and practices uncovered major tensions between the "physical and imagined realities of being a student within urban contexts" and the "students' developing views of themselves as doers of engineering" (p. 286). Classroom behavioral norms that prioritize compliance (e.g., rule-following, getting the answers "right," not getting into trouble) have been found in many schools, especially those where students of color are the predominant population. Students in these urban classrooms prioritized adherence to perceived established behavioral norms rather than deeply interrogating the pros and cons of each design before negotiating a design decision. Wright et al. (2018) argued for the necessity of renegotiating social norms around "engineering design practices, specifically argumentation and critique, in culturally sustaining ways" (p. 297).

English Learners (ELs)

English Learners often rely on modalities other than speech during communication as their language proficiency develops. As such, matters of access to engineering experiences for ELs involve understanding how these students communicate within these different modalities within engineering design teams. McVee et al. (2017) used a case study of a female, fourth-grade EL and her experience on an all-female, all-EL engineering design team to "provide a rationale for why educators and researchers need to move away from an almost exclusive focus on linguistic systems of meaning-making (e.g., printed word or spoken words) in classrooms" (p. 247). Instead, McVee and colleagues argued for the need to decentralize the privileged linguistic modality and attend broadly to how students (like ELs) may rely more on nonverbal modes of communication (e.g., touch, gesture, object-handling) as they interact with one another.

Similarly, Paugh et al. (2018) explored the case of a fifth-grade female student with developing English proficiency and how she successfully demonstrated and navigated both design- and teamwork-related demands as she flexibly leveraged academic linguistic genres (e.g., describing, explaining, logical argument in English and Spanish), interpersonal cues (e.g., acknowledging contributions, joint negotiation with teammate), and nonverbal modalities (e.g., gesturing shapes, manipulation of materials, sketching). This multimodal enactment of within-group engineering communicative practices was also demonstrated by Shanahan et al. (2018) discussing how technologies can be leveraged through tools found on mobile devices (e.g., photo/video camera, audio recorder, video editor) to create space and support for ELs in their sharing of design ideas with teammates.

Low Socioeconomic Status

In a case study of low-income students at an engineering summer camp, Maxey and Hynes (2018) hypothesized that within-group social status inequities might inhibit members' pursuit of engineering trajectories. The authors sought to understand the influence of within-group social status on peer interactions, group member positioning, and how such positioning influenced engagement "with engineering concepts, practices, and habits" (p. 1). High-status members tended to answer questions about design decisions when the opportunity arose whereas other students did not make such contributions. Low-status members were characterized by disengagement with the task, largely being ignored by teammates, and verbalizing their disinterest in engineering. This study indicated that social-interactional norms needed for equitable participation on design teams require intentional development with students before expecting students to complete this independently in small groups.

Gender

Any action toward building gender equity in engineering has necessitated the study of gender during interaction on design teams. Discourse analysis of collaborative group interactions of design teams was used to make comparisons between single-gender as well as mixed-gender design teams. Hudson and colleagues (2013) explored how members of one mixed-gender engineering design group learned about engineering concepts. Based on analyses of interactional data and the group's design work booklet, the researchers surmised that in order to engage productively in engineering design, middle school girls may need clarification on engineering terms to facilitate their discursive participation, nonjudgmental opportunities to clarify conceptual understandings, and multiple chances to manipulate materials.

Focusing on all-girl teams, Pattison and colleagues (2018) investigated how adolescent girls negotiated engineering-related identities as well as influenced their group members' understanding of engineering during collaborative engineering design challenges. The authors used an identity-frame model to compile profiles of each focal participant's identity negotiation style (e.g., group leader, collaborator, resource) enacted during collaborative engineering design projects. Pattison and colleagues found that the girls helped define engineering for their group members (e.g., as cooperative or as collaborative) and differentially supported or thwarted their group members' identity negotiation.

Schnittka and Schnittka (2016) examined both single-gender and mixed-gender grouping, studying communicative interaction styles on teams with respect to culturally situated gender norms and values (i.e., male individuals tend toward competition and are task-focused; female individuals are more people-oriented and more collaborative). Additionally, they evaluated content knowledge relevant to design problems for each student. These authors found that although interactional style looked different across gendered design teams, there was a tendency for single-gender groups to take on qualities of traditional gender interactional norms. Thus, with its detailed analysis of the talk in single-gender and mixed groups, the study illuminates inequities inherent within culturally situated gender norms found at micro-levels on design teams. Additionally, the authors argued for engineering instructors to become meta-aware about the genderedness of engineering and to facilitate meaningful engagement with the EDP by providing space for all students to struggle meaningfully with the design problem and materials.

In sum, the above eight articles explicitly focused on issues of equity and identity as related to K-12 communication practices in engineering design. Although these articles addressed access for particular underrepresented identity groups, more work needs to be done collectively on issues of equity related to communicative literacies in engineering. A notable forthcoming contribution in this area is that of Wilson-Lopez et al. (in press).

Learning STEM Content Through Engineering Design

As noted above, scholarly consideration of engineering disciplinary literacies has been complicated by the very nature of engineering as an interdisciplinary discipline. Along with the integration of engineering into national science standards has

come increasing interest in engineering design as a means to learn, apply, and connect concepts from across the STEM disciplines. Specific to our review, we identified six articles that investigated how within-group communication fosters knowledge and application of math, science, and technology concepts.

Multiple studies used integrated STEM content to engage their students in evidence-based reasoning practices. Siverling and colleagues authored two studies that drew from the NGSS call to connect all four STEM disciplines and to engage students in using science and engineering practices that promote such integration (NRC, 2012; NGSS Lead States, 2013). In an earlier section of their first study, Siverling et al. (2017) used the presence of science, engineering, and mathematical content in one design group's discourse as signs of evidence-based reasoning in within-group communication. Broadening the scope of the above analysis, Siverling and colleagues (2019) examined episodes of evidence-based reasoning in engineering teams engaged in STEM integrated curricular units. Fifteen STEM content categories were identified, indicating that students used content knowledge across all four STEM disciplines while generating and justifying design solutions. In a similar vein, Mathis and colleagues (2018) explored how students used science and math concepts while collaborating on an engineering design challenge during an integrated STEM unit designed with scaffolds for evidence-based reasoning. Content analysis of one team's response to the design challenge revealed that students used science and math concepts introduced during the problem scoping phase to defend design ideas and decisions while generating solutions, although not always exhibiting a complete understanding of some concepts.

Analyzing group interactions and design sketch workbooks, King and English (2017) reported that students applied core science, math, and technology concepts when they engaged in iterative design cycles to construct an optical instrument. Applications of STEM constructs occurred not only during group members' communication about sketches, but also during construction of their evolving working prototypes. Similarly, Guzey and Aranda (2017) studied how engineering design teams strove to apply science concepts, along with other stated constraints (i.e., budget), in their decision-making about building an effective greenhouse. Although students were asked to apply scientific knowledge pertaining to how temperatures affect different materials, teams struggled to apply such science concepts, typically basing their decisions exclusively on the cost of materials. This necessitated teacher intervention, reminding students to apply what they had learned about heat transfer in their decision-making processes.

Valtorta and Berland (2015) investigated similar issues in the context of a high school engineering course, finding that students frequently integrated familiar math and science concepts without teacher prompting while designing a pinhole camera. However, students were often not successful at integrating less familiar concepts regardless of explicit teacher prompting. Thus, unlike Guzey and Aranda (2017), Valtorta and Berland were unable to find any positive influence of teacher scaffolding on student outcomes.

In sum, the studies addressing how knowledge of key STEM concepts was used as students engaged in engineering design collaborations showed the promise, realized to varying degrees, of such engineering-focused activities for fostering the application of science, math, and technology knowledge. As students grappled with engineering design decisions, they encountered an opportunity to apply knowledge that may otherwise have remained only abstract.

Affective Responses to Uncertainty and Risk in Engineering Design

Engineering scholars generally have accepted the need to manage uncertainty as fundamental to engineering, as is the central role that coping with failure plays in the design process. Interestingly, the role of emotions in collaborative communicative practices has received very little attention in the K-12 communicative literacies literature, and it was only in one of the five articles we grouped in this theme that we saw some attention to affect. Across the following articles, two groups of scholars argued that engineering design projects present rare opportunities for young students to learn to cope with uncertainty and risk during design. Notably, no studies were identified of pre-college students' communicative literacies related to coping with failure.

In a series of studies, Jordan and colleagues argued that collaborative engineering design projects present particular affective challenges because they are fraught with uncertainty due to ambiguity, novelty, complexity, and social-interactional demands. Jordan (2010) identified the different sources of uncertainty salient for students across the phases of the EDP during a collaborative robotics project. In these projects, students had opportunities to recognize the appropriateness of experiencing uncertainty when practicing engineering and to discuss uncertainty productively during group sessions. Jordan and Babrow (2013) explored interactions in groups as they framed problems and generated solutions. Specifically, the ability to "suspend certainty" and "sustain uncertainty" by temporarily avoiding evaluation and premature closure on ideation was identified as critical and as a potentially optimal communicative literacy pattern (i.e., present idea, examine idea, amend idea, present new idea).

Jordan and McDaniel (2014) identified communicative strategies that group members used to reduce, maintain, intentionally increase, or ignore uncertainty during work sessions across two EDPs. Moreover, the authors found that peer

support is a critical resource for managing both social and task uncertainty. Finally, Jordan (2015) found that uncertainty management as a communicative act had bi-directional influence, with students evidencing different individual propensities for managing uncertainty that may influence their peers. Specifically, there were several different dispositions for managing uncertainty that varied by whether students were willing to acknowledge uncertainty to their peers and by the richness of their management strategies, sometimes in felicitous and sometimes in unhelpful ways.

A construct closely aligned with *uncertainty management* has been *risk management*. Unlike *uncertainty*, *risk* has emphasized individuals' perceptions of danger or threat associated with uncertain situations. Wright et al. (2018) identified collaborative design tasks as opportunities for risk taking and risk management during argumentation in design teams, portraying argumentation as both a tenet of collaborative reflective decision-making and one of an engineering identity. Being a "doer of engineering" for students in urban-characterized schools pointed toward tensions between demands for compliance found in authoritative discourses of their classroom (e.g., certainty of a "right answer" or avoiding risks of disagreeing with teachers or peers) and discourses of engineering taught as part of design units. Resolving this tension often resulted in students compromising on ideas in order to defuse disagreement, thereby limiting opportunities to engage in argumentation about optimal design solutions.

In sum, the above studies represented an abiding interest in how collaborative teamwork in engineering design enables and even highlights the need for young engineers-in-training to learn to "live" with uncertainty, to manage uncertainty originating from several aspects of the design process, and to take risks as they develop their engineering communicative literacies. These studies put into sharp relief a particular practice endemic to engineering design projects: the need for discourse in engineering teams to make room for the emotional responses that come with uncertainty and risk-taking in the service of finding design solutions to problems.

Evaluating Quality of Collaboration

Although many of the studies reviewed were concerned with improving students' communicative literacies associated with engineering design, only five articles focused on directly evaluating the quality of team collaboration. A notable feature among the upcoming studies was the diversity of definitions for collaboration quality, sometimes defined broadly as the teams' ability to address communication challenges (Jordan & DeLaRosa, 2017). Menekse and colleagues (2017) defined collaboration quality more specifically as "amount of discussion, depth of shared contributions building on one another's ideas, elaboration of one another's ideas, use of how and why questions in exploring one another's ideas, and joint nature of the decisions" (p. 571).

Wilson et al. (2014) compared the quality of interaction of two design groups, reporting that the design group characterized as enacting more collaborative practices was more successful at responding to an imagined client's needs than the other group. By *collaborative practices*, these authors meant annotating problem statements, prioritizing needs, and making inferences early in design. Similarly, Jordan and Babrow (2013) compared the quality of design teams' interactions during collective brainstorming sessions. By distinguishing sources of uncertainty salient to the EDP, and differentiating between probabilistic uncertainty (i.e., event likelihood) and evaluative uncertainty (i.e., ambiguity and value judgements), Jordan and Babrow identified patterns of talk that characterized more and less successful collaboration.

Responding to the current lack of instructional approaches supporting engineering communicative literacy practices among students, Jordan and DeLaRosa (2017) implemented a peer-observer innovation to help design teams negotiate challenges. Peer-observers recorded notes on how their assigned team negotiated roles and responsibilities, evaluated progress, understood the task, and generated design ideas. The peer-observers then met to debrief, compare notes, and generate suggestions for effective team communication that they collectively shared with their class as a whole. Interestingly, peer-observers attended to both social and task aspects of interactions across the EDP, suggesting the potential for a peer-observer approach to help young learners of engineering design acquire the communication practices of the discipline.

Finally, there were two research teams that used quantitative analytic techniques to investigate communicative literacies in pre-college settings (Menekse et al., 2017; Yuen et al., 2014). These studies were set in out-of-school, robotics engineering design contexts and used observational protocols with predetermined, quantifiable rubrics for collaboration quality during short researcher-developed collaborative tasks. Menekse et al. (2017) compared collaboration quality measured at the group level to objective measures of K-8 teams' project performance in a FIRST LEGO League competition. Measuring collaboration quality at the individual level, Yuen et al. (2014) determined predictors of on-task behavior of elementary and middle school design teams in a robotics camp. Across both studies, findings confirmed a positive relationship between high-quality within-group communication and group success.

The reviewed studies that explicitly set out to evaluate the quality of communication occurring in engineering teams uniformly confirmed a positive connection between high-quality communication and success in engineering design efforts.

Figure 2. Representation of the themes that emerged from the literature review of pre-college engineering disciplinary communicative literacies resulting in an engineering identity kit.

These results reinforce the need for scholars and practitioners to develop strategies for including communicative literacies in their instructional objectives for engineering-related instruction at the K-12 level.

Discussion and Considerations for Future Research

Responding to a call for research at the intersections of literacy, language, and engineering (Katehi et al., 2009), this state-of-the-art literature review illuminated a rich set of disciplinary practices pertaining to *communicative literacies* within K-12 engineering design teams. Taking an interdisciplinary stance, we located articles from journals across literacy education, STEM education, and education in general. The result was a body of literature serving dual purposes. First, this literature supports engineering educators seeking to emphasize small-group collaborative and communicative competencies to support pre-college engineering curriculum development (e.g., Moore et al., 2014). Additionally, this literature supports researchers studying discipline-specific literacy practices (e.g., Moje, 2008) as these pertain to emergent fields in K-12 education like engineering (e.g., Shanahan et al., 2016).

In Figure 2, we represent the conceptual structure and outcomes of this literature review by graphically portraying how our themes are related to one another. Two of the arrows at the top in Figure 2 represent the larger bases of literature that featured empirical research with K-12 students interacting in engineering design teams. The third of the top arrows depicts the influence of standards documents that have promoted the language-centric nature of collaborating in such teams. As well, our review was guided by the oft-stated need to develop better communicative literacies in pre-college engineering settings so that engineering college students are better prepared for the demands of the field (represented in Figure 2 by the side right-pointing arrow). Additionally, our review was motivated by the need for explicit guidance for productive within-group interaction (depicted by the left-pointing arrow). These perspectives as well as those afforded by a broad disciplinary literacies framework led us to synthesize our findings into five themes illustrated as boxes: (1) engineering disciplinary

communicative literacies, (2) matters of access for identity groups underrepresented in engineering, (3) learning STEM content through engineering design, (4) affective responses to uncertainty and risk in engineering design, and (5) evaluation of the quality of collaboration in engineering design. All five of these themes contribute to an understanding of an engineering identity kit (see lowest oval in Figure 2; Gee, 1998) as crucial in representing the socially situated practices and social languages, the very discourse involved in engineering.

Grant and Booth (2009) stated that the purpose of a state-of-the-art literature review is to depict the “current state of knowledge,” and we believe we have done so. As well, they claimed that an important aspect of such a review is to explicate “priorities for future investigation and research” (p. 95). Our review so far has endeavored to portray accurately the current state of knowledge pertaining to K-12 communicative literacies within the discipline of engineering. In the next section, we integrate across our five themes in order to propose considerations for future research within this interdisciplinary field of study, suggesting ways this literature could benefit from expanding its theoretical framing, its methodological approaches and tools, its pedagogical applications, and its connection to broader issues of identity, access, and equity.

Considerations of Theoretical Framing

Across the literature reviewed, we noticed several theoretical frameworks guiding the research on engineering communicative literacies conducted in K-12 educational contexts. Several studies used some sort of social theory, including sociocultural theory (Jung & McFadden, 2018; King & English, 2017), social constructivism (Hudson et al., 2013), situated learning (Guzey & Aranda, 2017; Wendell & Andrews, 2017; Wendell et al., 2019), situated cognition (King & English, 2017), as well as social semiotics with attention to multimodality (Jordan, 2010; McVee et al., 2017; Paugh et al., 2018; Shanahan et al., 2016, 2018). These frameworks are common to studies found in literacy and communication studies, as they support and robustly explain matters of communication and discourse. However, we also found articles that, though they were making claims about communication and discourse, did not rely on any social theory, or did so minimally. For example, Hertel and colleagues (2017) claimed that key communicative actions take place across nonlinguistic modalities. In our view, this claim could be strengthened by using theories originating in literacy research, such as multiliteracies (New London Group, 1996), and/or in communication studies, such as the social semiotic perspective of multimodality (Kress, 2010; Norris, 2004). This is one example of how taking an interdisciplinary approach to communication in K-12 engineering design teams could provide a nuanced theoretical framing and vocabulary through which to consider within-group interactions.

We also noticed that across our themes, affect and how it impacts communication in engineering design teams lacked deep theoretical framing. Specifically, the studies we clustered under the theme of affective practices in engineering design collaborations were few in number and were focused less on a deep appreciation of the affective experiences of team members than on examining responses to appraisals of uncertainty and risk (Jordan, 2010, 2015; Jordan & Babrow, 2013; Jordan & McDaniel, 2014; Wendell et al., 2018). The bounded nature of this set of affective considerations is surprising, given that a rich tapestry of affective experiences have been reported associated with collaborative interactions in general, including emotions, attitudes, motivation, and engagement (e.g., Kim et al., 2012; Park et al., 2019). Clearly we need to expand considerations of the affective dimensions afforded by engineering design activity in K-12 contexts. Also, more work is warranted on students' affective response to risk and their resilience in the face of engineering failure (see Andrews, 2017). Studies could benefit from using theoretical frameworks focused more specifically on affect. The control-value theory of achievement emotions developed by Pekrun (2006; Pekrun & Perry, 2015), for instance, provides a productive description of how emotions are elicited in and influence the ongoing experiences of students in any achievement situation. However, this theory has only rarely been used to explain affect in group processes (but see Linnenbrink-Garcia et al., 2011), let alone to describe the moment-to-moment affective experience of students when engaged in engineering teams.

Academic literature about engineering and engineering education frequently places communicative literacies alongside a host of nontechnical skills and habits of mind that are referred to as *professional skills* (replacing the earlier term *soft skills*; e.g., Pulko & Parikh, 2003). Studies and national reports describe the “T-shaped engineer” who is well versed in both technical and professional skills with depth and breadth in both sets of practices (see NAE, 2004; National Academies of Sciences, Engineering, and Medicine, 2016). Professional skills tend to include any practice outside the bounds of mathematical, scientific, and technical proficiencies. The vertical bar of the “T” represents an engineer's depth of knowledge and skill in their own area of emphasis. The horizontal beam represents their ability to collaborate across disciplines and to engage in *boundary-crossing skills* (Kassis-Henderson et al., 2018, p. 32) that are deemed important as engineering becomes more global, interdisciplinary, and team-oriented. It is on this boundary-crossing beam that one finds labels that we here associate with communicative literacies such as *teamwork*, *communication*, and *networking*. When these are joined with many other skills such as *multiple perspective-taking*, *critical thinking*, *creativity*, *leadership*, *project*

management, problem solving, this cluster of ideas becomes very broad, threatening to erase the power of communicative literacies as a critical competency needed in today's engineering practice.

In response, this review leads us to argue that there is a need for scholars to focus on students' ways of communicating in a team, recognizing that engineering is accomplished as a team (Hynes & Swenson, 2013). We seek to re-theorize these collaborative, communicative literacies as a distinct part of professional skills, as such skills seem to foster what Menekse et al. (2017) and Wilson et al. (2014) claimed make for more productive K-12 engineering teams. Most engineering projects are team-based, and learning how to convey one's ideas, designs, and critiques, as well as content and technical knowledge is essential to the success of the project. We assert that a stronger focus on communicative literacies as an integral component of engineering education will lead to a more complete and nuanced understanding of what is needed for preparing future engineers for a global industry. We propose that the field's understanding of professional skills will be enriched by communication and literacy frameworks that can be theoretically and methodologically useful in broader university and K-12 engineering education.

Considerations of Methodological Approaches and Framing

Representation of the themes that emerged from the literature review of pre-college engineering disciplinary communicative literacies resulting in an engineering identity kit has made it essential to apply methodological approaches, frameworks, and tools that lend themselves to the study of discourse. The studies we reviewed were specifically selected because their purpose (i.e., studying within-group communication) was well aligned with their methodologies. These methodologies included using observation with field notes (e.g., Hudson et al., 2013, Jung & McFadden, 2018), audio and visual transcripts of team communication (used by most of the studies reviewed here), and moment-by-moment discourse analysis of observation (e.g., Pattison et al., 2018; Schnittka & Schnittka, 2016; Siverling et al., 2017; Wright et al., 2018). The use of these methodological tools meant that most studies reviewed had a qualitative or mixed methods research design focused on observation and discourse of K-12 students in engineering design teams. Interestingly, though we only found two studies that were quantitative in nature (Meneske et al., 2017; Yuen et al., 2014), observation as a data source for within-group communication was still evident, now implemented through use of a quantifiable observation protocol to collect data rather than transcripts.

There are also studies in engineering education that have researched some facets of within-group communicative literacies (e.g., collaboration, interaction) that did not use observation or transcribed discourse as data. As examples, Bakar et al. (2013) used interviews and Likert surveys *after* engagement in engineering teamwork and Basu et al. (2015) defined collaboration as time-on-task in digital engineering team contexts. Although these indirect data points can be used as triangulation or secondary data sources for arguments about within-group communicative literacies, we contend that strong claims about such literacies need primary data sources of real-time interactions between group members. This is what nearly every study included in our review did, showing an alignment between methodology and purpose.

However, we want to offer that additional analytic tools and forms of data should be considered by the discourse analysts and qualitative observers interested in K-12 engineering communicative literacies that we reviewed. For example, close analysis of the gestures used by group members discussing scientific constructs have been shown to be deeply meaningful (Singer et al., 2008; Unsal et al., 2018) and could productively be added to the more traditional forms of discourse analysis currently used to describe engineering team collaborations. Similarly, careful detailing of body movements and positioning during classroom discussion has revealed how meaning is collaboratively constructed not only through words but also through the embodied response of the meaning maker (Rowe & Leander, 2005; see also Leander & Boldt, 2013), and such analysis would enrich the current qualitative work in this area. Finally, as a form of triangulation, quantitative sorts of data tools such as social network analysis may add to what discourse analysis reveals in collaborative work (Park et al., 2018; Wasserman & Faust, 2007).

Considerations of Pedagogical Support

The studies we reviewed collectively affirm a need for the intentional construction of habits of mind pertaining to engineering disciplinary communicative literacies (e.g., Dannels, 2001). Even at the college level, it is a common complaint that students arrive at their undergraduate engineering courses without the communicative practices needed for effective collaboration in small-group design teams (Moore-Russo et al., 2017). The K-12 engineering curriculum seems a natural place for explicit instruction in effective team collaboration. As Shanahan and colleagues (2016) explained in their model of productive communication, ongoing development of communicative capacities in the classroom contributes to students' successful joint negotiations and problem-solving. Scholars have recognized that within-group communication practices improve with experience (e.g., Hammond et al., 2011; Smith & Leong, 1998; Stempfle & Badke-Schaub, 2002).

Such development is more likely when teachers help their students learn about collaboration and group decision-making as an explicit instructional goal. Engineering is not simply a technical domain; it also requires team-based communicative skills (Leydens, 2012), and as such, educators can intentionally teach communicative literacies to emphasize these qualities of engineering to newcomers to the field.

Along similar lines, Wilson-Lopez and colleagues (2018) have advocated for a need to further understand how argumentation is used within K-12 engineering, particularly in ways that further elaborate the complexities of argumentation as a process and elucidate distinctions between argumentation in science and in engineering. As shown in literacy studies, even early elementary school students can learn how to engage in productive talk with each other about literature, respectfully arguing for their interpretations of text and seeing their work as a joint enterprise of meaning making (Clark et al., 2003; Murphy et al., 2018). From a pedagogical standpoint, there is a need for elaboration of research-supported guiding principles about how specifically to facilitate the development and assessment of high-quality engineering communicative literacies within design teams (Jordan & DeLaRosa, 2017; Wilson et al., 2014). Not only is this kind of engineering education useful for students who go on to engineering majors and careers, it is also useful to K-12 students in general, as the need for competency in communicative literacy practices means that their engineering communicative experiences will serve them well in other spaces.

Bringing It All Together: Considerations of Engineering Identity Development

One reason that engineering education has become important in K-12 education is the increasing demand for individuals to enter the field in the upcoming decades (NAE, 2004). Unlike other professions that children can more readily envision (e.g., teacher, doctor, chef), engineers are often misconceptualized or not understood at all in terms of their practices, discourse, roles in society, and ultimately, their identities (Capobianco et al., 2011). In order for K-12 students to see themselves as future engineers, they need not only to have an understanding of what engineers do but also to develop within themselves the seeds of engineering identities (Capobianco et al., 2012; Yoon et al., 2014). The development of any kind of identity requires what literacy researcher James Gee (1998) called an *identity kit*, or the different aspects of discourse that are “the appropriate costume and instructions on how to act and talk so as to take on a particular role that others will recognize” (p. 51). Taken together, we find that the five themes in our review encompassed how communicative literacies in engineering bring in the different elements of an engineering identity kit, and that these suggest ways to foster engineering identities in K-12 students (also represented in Figure 2).

The theme *engineering disciplinary communicative literacies* as well as that of *affective responses to uncertainty and risk in engineering design* reveal multiple, socially situated communicative practices in which engineering design teams engage. These practices relating to engineering design work (e.g., negotiating, consensus-building, decision-making, evidence-based reasoning) as well as managing a team’s affective responses during this work (e.g., coping with failure) help constitute a social language that is routine within engineering. *Social languages* are “ways with words (oral and written) within Discourses that relate form and meaning so as to express specific socially situated identities and activities” (Gee, 2018, p. 112). When K-12 students engage in these practices in engineering design teams, they can acquire social languages inherent to engineering. Acquiring these practices and their related discourses supports students’ engineering identity development.

Gee (1998) proposed that when students are socialized into a new discourse, they cannot simply be taught its practices and social languages. Instead, they need the opportunity to acquire the language through the modeling of these activities in “natural settings which are meaningful and functioning in the sense that the acquirer knows that [they need] to acquire the thing [they are] exposed to in order to function and the acquirer in fact wants to so function” (Gee, 1998, p. 53). The theme of *learning STEM content through engineering design* provides the “meaningful and functioning” settings for students as budding engineers to apply and deepen their acquisition of social languages and practices of engineering.

When considering the theme *evaluating quality of collaboration in engineering design*, researchers engage in a metalevel activity relating to the cultural model of engineering through their analysis of the quality of collaboration within K-12 design teams. Cultural models are “often tacit and taken-for-granted schemata, story lines, theories, images, or representations... that tell a group of people within a Discourse what is typical or normal from the point of view of that Discourse” (Gee, 2018, p. 112). Part of the cultural model of engineering discourse is that collaboration typically takes place in an engineering design team. However, the studies within this theme interrogate that cultural model, questioning and analyzing the quality of the collaborative practice itself. Understanding reasons *why* a particular group is more or less effective in terms of collaboration seems a worthy research endeavor, such as looking into the impact of individual team members’ personalities and skill sets (Yuen et al., 2014), patterns of interaction that arise at the collective level (Jordan & Babrow, 2013), or elements of the collaborative activity itself (Menekse et al., 2017).

Finally, in the theme *matters of access for identity groups underrepresented in engineering*, the issue of “Who gets to be an engineer?” is critically considered. This speaks directly to the current cultural model of engineering, one where girls, ELs, and specific racial and ethnic minorities are rare, almost invisible, and/or unwelcome. For all the attention given to issues of diversity in the engineering profession, more is still needed in attending to gender, language, racial, and ethnic identities. By emphasizing the central role that communicative practices play in engineering, we as researchers are encouraged to tackle issues of whose voice, whose point of view, and whose design idea gets taken up in a collaborative engineering team.

Conclusion

As K-12 education efforts prepare students for rapidly expanding career opportunities in engineering fields, it becomes necessary to consider how students and teachers make sense of the discourses and communicative practices pertinent to engineering. This state-of-the-art literature review both revealed the scope and characteristics of K-12 engineering communicative literacies research and offered literacy frameworks that can provide deeper theoretical and methodological insights into engineering communicative literacy skills. We conclude with two final points.

First, scholars need to recognize difficulties inherent in conducting research in such interdisciplinary fields. Part of the challenge of interdisciplinary work is finding relevant and/or connected work in the respective fields. Rising to this challenge, we not only searched databases for relevant studies but also performed a hand search over the past 10 years of three general education journals, four engineering journals and conference proceedings, six science/STEM journals, and nine literacy journals. Even with this interdisciplinary search, each author of this review is aware of work that did not surface in the search results involving group interaction and dynamics in pre-college engineering design teams (e.g., McCormick & Hammer, 2014; McNeill & Martin, 2011). Although these articles ultimately do not fully meet the criteria for inclusion in this review, we recognize that they are nevertheless connected to the larger conversation at hand. Moving forward, scholars interested in working at the intersection of engineering and literacies ought to establish clear criteria about what might count as engineering practices, even when such work may not explicitly refer to *engineering* per se (e.g., design; problem- and project-based learning).

Second, research into communicative literacies in pre-college engineering contexts also indicates the importance for stakeholders to clarify the nature of engineering and its particular disciplinary demands. Currently, calls for explicit cross-curricular connections among STEM, language, and literacy pedagogies for K-12 practitioners request greater recognition of engineering as a specific set of disciplinary understandings (e.g., Pleasants & Olson, 2018). Although science and engineering share similar tenets, there are dimensions of necessary difference that research on within-group communicative literacies can help unravel. Additionally, we suggest that explorations of the discourses specific to engineering broaden their focus to include underrepresented grade bands (i.e., early elementary grades, high school) within this study area. Literacy research and communication studies clearly have much to offer the field of engineering in an interdisciplinary partnership. Concomitantly, engineering aims higher education to disciplinary and critical literacies that support asset-based pedagogy in K-8 urban classrooms.

Author Bios

Katarina N. Silvestri is an assistant professor of literacy education at SUNY Cortland (Cortland, NY). Dr. Silvestri conducts research pertaining to multimodal literacy practices, inquiry-based research in elementary schools, and online learning in higher education.

Email: katarina.silvestri@cortland.edu

Michelle E. Jordan is an associate professor in the Mary Lou Fulton Teachers College at Arizona State University. Dr. Jordan conducts research on K-12 collaborative engineering design work. She is particularly interested in how youth use social relationships to manage uncertainty.

Email: michelle.e.jordan@asu.edu

Patricia Paugh is an associate professor in the College of Education and Human Development at the University of Massachusetts Boston. Dr. Paugh conducts research focusing on questions related to disciplinary and critical literacies that support asset-based pedagogy in K-8 urban classrooms.

Email: patricia.paugh@umb.edu

Mary B. McVee is Professor of Literacy Education and Director of the Center for Literacy and Reading Instruction at the University of Buffalo, SUNY. Dr. McVee conducts work on engineering and disciplinary literacies for elementary students using lenses of positioning theory, equity, and multimodality.

Email: mcvee@buffalo.edu

Diane L. Schallert is a professor of Educational Psychology at the University of Texas at Austin with research interests in how people learn broadly, the motivational and emotional work involved in learning, and how language and literacy intersect the learning process.

Email: dschallert@austin.utexas.edu

Acknowledgments

We express our gratitude to Dr. Jess Swenson for providing us her expertise as an outside reader for this review. We also extend thanks to Kelly Schucker for her hard work and attention to detail as an editor for our initial drafts of this literature review.

References

- Accreditation Board for Engineering and Technology. (2020, Jan 28). *Criteria for accrediting engineering programs, 2020-2021*. [Online]. Available at <https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/>
- American Society for Engineering Education. (2018). *Annual conference—overview*. Retrieved from <https://www.asee.org/conferences-and-events/conferences/annual-conference/2019>
- Andrews, C. J. (2017). *Elementary students' engagement in failure-prone engineering design tasks* (Doctoral dissertation). Tufts University, Medford, MA.
- Aurigemmma, J., Chandrasekharan, S., Nersessian, N. J., & Newstetter, W. (2013). Turning experiments into objects: The cognitive processes involved in the design of a lab-on-a-chip device. *Journal of Engineering Education*, 102(1), 117–140.
- Bakar, A. A. A., Nordin, R., Zainal, N., Alavi, K., Mustafa, M. M., & Hussain, H. (2013). Nurturing engineering enthusiasm and soft skills in high school students. *International Journal of Engineering Education*, 29(4), 933–939.
- Barr, R. E., Krueger, T. J., & Aanstoos, T. A. (2002). The new digital engineering design and graphics process. *Engineering Design Graphics Journal*, 66(3), 6–11.
- Basu, S., Kinnebrew, J. S., Shekhar, S., Caglar, F., Rafi, T. H., Biswas, G., & Gokhale, A. (2015). Collaborative problem-solving using a cloud-based infrastructure to support high school STEM education. *Proceedings of the 2015 ASEE Annual Conference & Exposition* (Paper ID 13785). Seattle, WA.
- Bazerman, C. (1985). Physicists reading physics. *Written Communication*, 2, 3–23.
- Bowers, N., Jordan, M. Evans, M., Fischer, K., & Holman, Z. (2019). Framing a research experience for undergraduates using a model of engineering practices in a community of practice. *Proceedings of the 2019 ASEE Conference*. Tampa, FL.
- Brock, C. H., Goatley, V. J., Raphael, T. E., Trost-Shahata, E., & Weber, C. M. (2014). *Engaging students in disciplinary literacy, K-6: Reading, writing, and teaching tools for the classroom*. Teachers College Press.
- Capobianco, B. M., Diefes-Dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education? *Journal of Engineering Education*, 100(2), 304–328.
- Capobianco, B. M., French, B. F., & Diefes-Dux, H. A. (2012). Engineering identity development among pre-adolescent learners. *Journal of Engineering Education*, 101(4), 698–716.
- Cervetti, G. N., Barber, J., Dorph, R., Pearson, P. D., & Goldschmidt, P. G. (2012). The impact of an integrated approach to science and literacy in elementary school classrooms. *Journal of Research in Science Teaching*, 49(5), 631–658.
- Cervetti, G., & Pearson, P. D. (2012). Reading, writing, and thinking like a scientist. *Journal of Adolescent & Adult Literacy*, 55(7), 580–586.
- Cerato, A., Elton, D., & Shannon, D. (2011). Building student teamwork with the student geo-challenge. *Journal of Professional Issues in Engineering Education & Practice*, 138(1), 14–20.
- Clark, A.-M., Anderson, R. C., Kuo, L.-J., Kim, I.-H., Archodidou, A., & Nguyen-Jahiel, K. (2003). Collaborative reasoning: Expanding ways for children to talk and think in school. *Educational Psychology Review*, 15(2), 181–198.
- Cunningham, C., & Kelly, G. J. (2017). Epistemic practices of engineering for education. *Science Education*, 101(13), 486–505.
- Dannels, D. P. (2001). Time to speak up: A theoretical framework of situated pedagogy and practice for communication across the curriculum. *Communication Education*, 50(2), 144–158.
- Dannels, D. P., Anson, C., Bullard, L. G., & Peretti, S. (2003). Challenges in learning communication skills in chemical engineering. *Communication Education*, 52, 50–56.
- Darling, A. L., & Dannels, D. P. (2003). Practicing engineers talk about the importance of talk: A report on the role of oral communication in the workplace. *Communication Education*, 52, 1–16.
- Diaz, N. V., & Cox, M. F. (2012). An overview of the literature: Research in P-12 engineering education. *Advances in Engineering Education*, 3(2), 1–37.
- Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 94(1), 103–120.
- Fang, Z. (2012). Language correlates of disciplinary literacy. *Topics in Language Disorders*, 32(1), 19–34.
- Flury-Kashmanian, C. (2016). Engineers reading disciplinary texts: Skimming for “shiny objects” and tapping into knowledge and experience (Unpublished doctoral dissertation). University at Buffalo, SUNY, Buffalo, NY.
- Frankel, K. K., Becker, B. L., Rowe, M. W., & Pearson, P. D. (2016). From “what is reading?” to what is literacy? *Journal of Education*, 196(3), 7–17.
- Frey, N., Fisher, D., & Everlove, S. (2009). Productive group work: How to engage students, build teamwork and promote understanding. ASCD.

- Gee, J.P. (1998) What is literacy? In V. Zamel & R. Spack (Eds.), *Negotiating academic literacies: Teaching and learning across languages and cultures* (pp. 51–59). Mahwah, NJ: Lawrence Erlbaum.
- Gee, J. P. (2018). Reading as situated language: A sociocognitive perspective. In D.E. Alvermann, N.J. Unrau, M. Sailors, & R.B. Ruddell (Eds.), *Theoretical models and processes of literacy* (7th ed.) (pp. 105–117). Newark, DE: International Reading Association.
- Geisler, C., & Lewis, B. (2000). Talking to texts and sketches: The function of written and graphic mediation in engineering design. *Business Communication Quarterly*, 63(2), 110–116.
- Giroux, C., & Moje, E. B. (2017). Learning from the professions: Examining how, why, and when engineers read and write. *Theory into Practice*, 56, 300–307.
- Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), 91–108.
- Grapin, S. (2019). Multimodality in new content standards era: Implications for English learners. *TESOL Quarterly*, 53(1), 30–55.
- Gorman M. E. (Ed.). (2010). *Trading zones and interactional expertise: Creating new kinds of collaboration*. MIT Press.
- *Guzey, S., & Aranda, M. (2017). Student participation in engineering practices and discourse: An exploratory case study. *Journal of Engineering Education*, 106(4), 585–606.
- Hammond, J., Koubek, R. J., & Harvey, C. M. (2001). Distributed collaboration for engineering design: A review and reappraisal. *Human Factors and Ergonomics in Manufacturing*, 11, 35–52.
- Hart, S. M., & Bennett, S. M. (2013). Disciplinary literacy pedagogy development of STEM preservice teachers. *Teacher Education & Practice*, 26(2), 221–241.
- Henderson, K. (1991). Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. *Science, Technology, & Human Values*, 16(4), 448–473.
- *Hertel, J. D., Cunningham, C. M., & Kelly, G. J. (2017). The roles of engineering notebooks in shaping elementary engineering student discourse and practice. *International Journal of Science Education*, 39(9), 1194–1217.
- Hillman, A. M. (2014). A literature review on disciplinary literacy: How do secondary teachers apprentice students into mathematical literacy? *Journal of Adolescent & Adult Literacy*, 57(5), 397–406.
- Ho, M. (2011). Academic discourse socialization through small-group discussions. *System*, 39, 437–450.
- Holmes, J., & Woodhams, J. (2013). Building interaction: The role of talk in joining a community of practice. *Discourse & Communication*, 7(3), 275–298.
- *Hudson, P., English, L. D., & Dawes, L. (2013). Female students' interactions in a middle school engineering project: A case study. *International Journal of Engineering Education*, 29(4), 814–821.
- Hynes, M. M., Mathis, C., Purzer, S., Rynearson, A., & Siverling, E. (2017). Systematic review of research in P-12 engineering education from 2000-2015. *International Journal of Engineering Education*, 33(1), 453–462.
- Hynes, M., & Swenson, J. (2013). The humanistic side of engineering: Considering social science and humanities dimensions of engineering in education and research. *Journal of Pre-College Engineering Education Research*, 3, 31–42.
- Johri, A., Roth, W. M., & Olds, B. M. (2013). The role of representations in engineering practices: Taking a turn towards inscriptions. *Journal of Engineering Education*, 102(1), 2–19.
- Jordan, M. E. (2014). Interweaving the digital and physical worlds in collaborative project-based learning experiences. In D. J. Loveless, B. Griffith, M. Berci, E. Ortlieb, & P. Sullivan (Eds.), *Academic knowledge construction and multimodal curriculum development* (pp. 266–284). Hershey, PA: IGI Global.
- *Jordan, M. E. (2010). Collaborative robotics engineering projects: Managing uncertainty in multimodal literacy practice in a fifth-grade class. *Yearbook of the National Reading Conference*, 59, 260–275.
- *Jordan, M. E. (2014). How design critique processes influence fifth-graders' peer interaction in collaborative engineering projects. *Proceedings of the 2014 ASEE Annual Conference & Exposition* (Paper ID 10605). Indianapolis, IN.
- *Jordan, M. E. (2015). Variation in students' propensities for managing uncertainty. *Learning and Individual Differences*, 38, 99–106.
- *Jordan, M. E., & Babrow, A. S. (2013). Communication in creative collaborations: The challenges of uncertainty and desire related to task, identity, and relational goals. *Communication Education*, 62(2), 210–232.
- *Jordan, M. E., & DeLaRosa, M. (2017). Investigating peer observers' perspectives on middle school engineering designers' communication challenges. *Proceedings of the 2017 Annual Conference & Exposition* (Paper ID 20148). Columbus, OH.
- *Jordan, M. E., & McDaniel Jr, R. R. (2014). Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences*, 23(4), 490–536.
- *Jung, K. G., & McFadden, J. (2018). Student justifications in engineering design descriptions: Examining authority and legitimacy. *International Journal of Education in Mathematics Science and Technology*, 6(4), 398–423.
- Kassis-Henderson, J., Cohen, L., & McCulloch, R. (2018). Boundary crossing and reflexivity: Navigating the complexity of cultural and linguistic identity. *Business and Professional Communication Quarterly*, 81(3), 304–327.
- Katehi, L., Pearson, G., & Feder, M. (2009). The status and nature of K-12 engineering education in the United States. *The Bridge*, 39(3), 5–10.
- Kedrowicz, A. A., & Taylor, J. L. (2013). Engineering communication and the global workplace: Preparing professionals and global citizens. *Connexions International Professional Communication Journal*, 1, 81–105.
- Kelly, G. J., Cunningham, C. M., & Ricketts, A. (2017). Engaging in identity work through engineering practices in elementary classrooms. *Linguistics and Education*, 39, 48–59.
- Kim, J. I., Kim, M., & Svinicki, M. D. (2012). Situating students' motivation in cooperative learning contexts: Proposing different levels of goal orientations. *Journal of Experimental Education*, 80(4), 352–385.
- *King, D. T., & English, L.D. (2017). Engineering design in the primary school: Applying stem concepts to build an optical instrument. *International Journal of Science Education*, 38(18), 2762–2794.
- Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication*. Routledge.
- Leander, K., & Boldt, G. (2013). Rereading “A pedagogy of multiliteracies”: Bodies, texts, and emergence. *Journal of Literacy Research*, 45(1), 22–46.
- Lee, O., Llosa, L., Grapin, S., Haas, A., & Goggins, M. (2019). Science and language integration with English learners: A conceptual framework guiding instructional materials development. *Science Education*, 103(2), 317–337.

- Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher*, 42(4), 223–233.
- Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex Publishing.
- Lewis, B. (2000). Talking to texts and sketches: the function of written and graphic mediation in engineering design. *Business Communication Quarterly*, 63(2), 110–116.
- Leydens, J. A. (2012). Sociotechnical communication in engineering: An exploration and unveiling of common myths. *Engineering Studies*, 4(1), 1–9.
- Linnenbrink-Garcia, L., Rogat, T. K., & Koskey, K. L. K. (2011). Affect and engagement during small group instruction. *Contemporary Educational Psychology*, 36, 13–24.
- Lwin, S. M., Goh, C., & Doyle, P. (2012). “I’m going to split you all up”: examining transitions to group/pair work in two primary English classrooms. *Language and Education*, 26(1), 19–33.
- Manderino, M. (2012). Disciplinary literacies in new literacies environments: Expanding the intersections of literate practices for adolescents. *61st Yearbook of the Literacy Research Association*, 61, 119–133.
- Marshall, J. A., & Berland, L. K. (2012). Developing a vision of pre-college engineering education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 2(2), 36–50.
- Martin, K. N., & Gaffney, A. L. H. (2016). INSIGHT Telling and showing: The intersection of visual communication content knowledge and pedagogical strategies in STEM. *Visual Communication Quarterly*, 23(2), 108–121.
- *Mathis, C. A., Siverling, E. A., Glancy, A. W., Guzey, S. S., & Moore, T. J. (2016). Students’ use of evidence-based reasoning in K-12 engineering: A case study. *Proceedings of the 2016 ASEE Annual Conference & Exposition* (Paper ID 16961). New Orleans, LA.
- *Mathis, C. A., Siverling, E. A., Moore, T. J., Douglas, K. A., & Guzey, S. S. (2018). Supporting engineering design ideas with science and mathematics: A case study of middle school life science students. *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, 6(4), 424–442.
- *Maxey, K. R., & Hynes, M. M. (2018). Equity in collaboration: My ideas matter, too! K-12 students’ negotiation of social status in collaborative engineering teams. *Proceedings of the 2018 ASEE Annual Conference & Exposition* (Paper ID 23250). Salt Lake City, UT.
- McCormick, M. E., & Hammer, D. (2014). Stable beginnings in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)*, 6(1), 45–54.
- McNeill, K. L., & Martin, D. M. (2011). Claims, evidence, and reasoning: Demystifying data during a unit on simple machines. *Science and Children*, 48(8), 52–56.
- McVee, M. B., Shanahan, L. E., & English, K. E. (2017). Disciplinary literacies and engineering [Themed issue]. *Theory Into Practice*, 56(4).
- *McVee, M. B., Silvestri, K., Shanahan, L., & English, K. (2017). Productive communication in an afterschool engineering club with girls who are English language learners. *Theory into Practice*, 56(4), 246–254.
- *Menekse, M., Higashi, R., Schunn, C. D., & Baehr, E. (2017). The role of robotics teams’ collaboration quality on team performance in a robotics tournament. *Journal of Engineering Education*, 106(4), 564–584.
- Moje, E. B. (2007). Developing socially just subject matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education*, 31 (3), 1–44.
- Moje, E. B. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy*, 52(2), 96–107.
- Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research (J-PEER)*, 4(1), 1–13.
- Moore-Russo, D., Wilsey, J. N., Parthum, M. J., & Lewis, K. (2017). Navigating transitions: Challenges for engineering students. *Theory into Practice*, 56(4), 291–299.
- Murphy, P. K., Greene, J. A., Firetto, C. M., Hendrick, B. D., Li, M., Montalbano, C., & Wei, L. (2018). Quality talk: Developing students’ discourse to promote high-level comprehension. *American Educational Research Journal*, 55(5), 1113–1160.
- National Academies of Sciences, Engineering, and Medicine. (2016). *Science literacy: Concepts, contexts, and consequences*. National Academies Press.
- National Academy of Engineering. (2004). *The engineer of 2020: Visions of engineering in the new century*. National Academies Press.
- National Academy of Engineering. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academies Press.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
- New London Group (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, 66 (1), 60–93.
- NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.
- Norris, S. (2004). *Analyzing multimodal interaction: A methodological framework*. Routledge.
- Park, J. J., Choe, H. N., Schallert, D. L., & Forbis, A. K. (2017). The chemical engineering research laboratory as context for graduate students’ training: The role of lab structure and cultural climate in collaborative work. *Learning, Culture and Social Interaction*, 13, 113–122.
- Park, J. J., Park, S., Choe, N. H., & Schallert, D. L. (2019). When groups experience conflict: Intersection among undergraduates’ individual and group motivational goals, project commitment, and emotions. *Educational Psychology*, 39(9), 1156–1173. Doi: 10.1080/01443410.2019.1618444
- Park, J. H., Williams, K. M., Choi, E., Lee, J. J., Gaines, R. E., Schallert, D. L., & Zengilowski, A. (2018, April). Between centrality and peripherality: A social network analysis of preservice teachers’ participation in online discussions. Paper presented at the annual meeting of the American Educational Research Association, New York, NY.
- *Paugh, P., Wendell, K., & Wright, C. (2018). Elementary engineering as a synergistic site for disciplinary and linguistic learning in an urban classroom. *Literacy Research: Theory, Method and Practice*, 67(1), 261–278.
- *Pattison, S. A., Gontan, I., Ramos-Montañez, S., & Moreno, L. (2018). Identity negotiation within peer groups during an informal engineering education program: The central role of leadership-oriented youth. *Science Education*, 102(5), 978–1006.
- Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, 18, 315–341.
- Pekrun, R., & Perry, R. P. (2015). Control-value theory of achievement emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *Handbook of emotions and education* (pp. 120–141). Routledge.
- Pleasant, J., & Olson, J. K. (2018). What is engineering? Elaborating the nature of engineering for K-12 education. *Science Education*, 103, 145–166.

- Pulko, S. H., & Parikh, S. (2003). Teaching 'soft' skills to engineers. *International Journal of Electrical Engineering Education*, 40(4), 243–254.
- Rainey, E., & Moje, E. B. (2012). Building insider knowledge: Teaching students to read, write, and think within ELA and across the disciplines. *English Education*, 45(1), 71–90.
- Rodriguez, A. J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. *Journal of Research in Science Teaching*, 52(7), 1031–1051.
- Roozen, K. (2010). Tracing trajectories of practice: Repurposing in one student's developing disciplinary writing processes. *Written Communication*, 23(3), 318–354.
- Roth, W. M. (2001). Gestures: Their role in teaching and learning. *Review of Educational Research*, 71(3), 365–392.
- Rowe, D. W., & Leander, K. M. (2005). Analyzing the production of third space in classroom literacy events. *National Reading Conference Yearbook*, 54, 318–333.
- Royal Academy of Engineering. (2014). *Thinking like an engineer: Implications for the education system*. Retrieved from <http://www.raeng.org.uk/thinkinglikeanengineer>
- *Rynearson, A. M., Moore, T. J., Tank, K. M., & Gajdzik, E. (2017). Evidence-based reasoning in a kindergarten classroom through an integrated STEM curriculum (fundamental). *Proceedings of the 2017 ASEE Annual Conference & Exposition* (Paper ID 20094) Columbus, OH.
- *Schnittka, J., & Schnittka, C. (2016). "Can I drop it this time?" Gender and collaborative group dynamics in an engineering design-based afterschool program. *Journal of Pre-College Engineering Education Research (J-PEER)*, 6(2), 1–24.
- Schön, D. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems*, 5, 3–14.
- *Shanahan, L. E., McVee, M. B., Silvestri, K. N., & Haq, K. (2016). Disciplinary literacies in an engineering club: Exploring productive communication and the engineering design process. *Literacy Research: Theory, Method, and Practice*, 65(1), 404–420.
- *Shanahan, L. E., Silvestri, K. N., & McVee, M. B. (2018). Digital engineering design team journals: Providing multimodal opportunities for English learners to explain design choices. *Journal of Adolescent & Adult Literacy*, 61(4), 445–451.
- Singer, M., Radinsky, J., & Goldman, S. R. (2008). The role of gesture in meaning construction. *Discourse Processes*, 45, 365–386.
- *Siverling, E. A., Suazo-Flores, E., Mathis, C. A., Moore, T. J., Guzely, S. S., & Whipple, K. S. (2017). Middle school students' engineering discussions: What initiates evidence-based reasoning? *Proceedings of the 2017 ASEE Annual Conference & Exposition* (Paper ID 19948). Columbus, OH.
- *Siverling, E. A., Suazo-Flores, E., Mathis, C. A., & Moore, T. J. (2019). Students' use of STEM content in design justifications during engineering design-based STEM integration. *School Science and Mathematics*, 119(8), 457–474.
- Smagorinsky, P., Cook, L. S., & Reed, P. M. (2005). The construction of meaning and identity in the composition of an architectural text. *Reading Research Quarterly*, 40(1), 70–88.
- Smith, R., & Leong, A. (1998). An observational study of design team process: A comparison of student and professional engineers. *Journal of Mechanical Design*, 120, 636–642.
- Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, 31(3), 459–480.
- Stempfle, J., & Badke-Schaub, P. (2002). Thinking in design teams: An analysis of team communication. *Design Studies*, 23(5), 473–496.
- Unsal, Z., Jakobson, B., Wickman, P., & Molander, B. (2018). Gesticulating science: Emergent bilingual students' use of gestures. *Journal of Research in Science Teaching*, 55(1), 121–144.
- *Valtorta, C. G., & Berland, L. K. (2015). Math, science, and engineering integration in a high school engineering course: A qualitative study. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(1), 15–29.
- Wasserman, S., & Faust, K. (2007). *Social network analysis*. New York, NY: Cambridge University Press.
- *Watkins, J., Spencer, K., & Hammer, D. (2014). Examining young students' problem scoping in engineering design. *Journal of Pre-College Engineering Education Research (J-PEER)*, 4(1), 43–53.
- *Wendell, K. B., & Andrews, C. J. (2017). Elementary student engagement with digital engineering notebook cards. *Proceedings of the 2017 ASEE Annual Conference & Exposition* (Paper ID 19872). Columbus, OH.
- *Wendell, K. B., Andrews, C. J., & Paugh, P. (2019). Supporting knowledge construction in elementary engineering design. *Science Education*, 103(4), 952–978.
- *Wendell, K. B., Wright, C. W., & Paugh, P. (2015). Urban elementary school students' reflective decision making during formal engineering learning experiences. *Proceedings of the 2015 ASEE Annual Conference & Exposition* (Paper ID 13735). Seattle, WA.
- *Wendell, K. B., Wright, C. G., & Paugh, P. (2017). Reflective decision-making in elementary students' engineering design. *Journal of Engineering Education*, 106(3), 356–397.
- *Wilson, A. A., Smith, E., & Householder, D. L. (2014). Using disciplinary literacies to enhance adolescents' engineering design activity. *Journal of Adolescent & Adult Literacy*, 57(8), 676–686.
- Wilson-Lopez, A. A., Mejia, J. A., Hasbun, I. M., & Kasun, G. S. (2016). Latina/o adolescents' funds of knowledge related to engineering. *Journal of Engineering Education*, 105, 278–311.
- Wilson-Lopez, A., Sias, C. M., Strong, A. R., Garlick, J. W., Minichiello, A., Acosta Feliz, J. A., & Weingart, S. (2018). Argumentation in K-12 engineering education: A review of the literature (fundamental). *Proceedings of the 2018 ASEE Annual Conference & Exposition* (Paper ID 22301), Salt Lake City, UT.
- Wilson-Lopez, A., Strong, K., & Sias, C. (2017). Critical literacy, disciplinary literacy: Reading the engineering-designed world. *Theory Into Practice*, 56(4), 238–245.
- Wilson-Lopez, A. A., Tucker-Raymond, E., Esquinca, A., & Mejia, J. (Eds.) (in press). *The literacies of design: Studies of equity and imagination with engineering and making*. West Lafayette, IN: Purdue University Press.
- *Wright, C., Wendell, K. B., & Paugh, P. P. (2018). "Just put it together to make no commotion": Re-imagining urban elementary students' participation in engineering design practices. *International Journal of Education in Mathematics, Science and Technology*, 6(3), 285–301.
- Wright, T. S., & Domke, L. M. (2019). The role of language and literacy in K-5 science and social studies standards. *Journal of Literacy Research*, 51(1), 5–29.
- Yoon, S. Y., Lucietto, A. M., Capobianco, B. M., Dyehouse, M., & Diefes-Dux, H. A. (2014). The effects of integrated science, technology, and engineering education on elementary students' knowledge and identity development. *School Science and Mathematics*, 114(8), 380–391.

- Yore, L., Bisanz, G. L., & Hand, B. M. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education*, 25(6), 689–725.
- *Yuen, T., Boecking, M., Stone, J., Tiger, E. P., Gomez, A., Guillen, A., & Arreguin, A. (2014). Group tasks, activities, dynamics, and interactions in collaborative robotics projects with elementary and middle school children. *Journal of STEM Education*, 15(1), 39–45.
- * Indicates reference for research article included in review.