International Journal of Education in Mathematics, Science and Technology

ISSN: 2147-611X

International Journal of Education in Mathematics, Science and Technology (IJEMST)

www.ijemst.com

Student Justifications in Engineering Design Descriptions: Examining Authority and Legitimation

Karl G. Jung[1], Justin McFadden[2]
[1]University of South Florida
[2]University of Louisville

To cite this article:

Jung, K.G. & McFadden, J. (2018). Student justifications in engineering design descriptions: Examining authority and legitimation. *International Journal of Education in Mathematics, Science and Technology (IJEMST), 6*(4), 398-423. DOI:10.18404/ijemst.440342

International Journal of Education in Mathematics, Science and Technology

Volume 6, Number 4, 2018 DOI:10.18404/ijemst.440342

Student Justifications in Engineering Design Descriptions: Examining Authority and Legitimation

Karl G. Jung, Justin McFadden

Article Info

Article History

Received:
01 July 2017

Accepted:
06 December 2017

Keywords

Elementary teaching
Engineering education
Discourse analysis
Student justifications

Abstract

The process of design is a key component of engineering that relies heavily on student collaboration and language use. One important aspect of design is the need for designers to develop solutions capable of solving specific engineering problems. Engineers enact recognizable epistemic practices and often rely on data as a means for justifying their designed solutions. Indeed, when striving to meet a specific client's requests, engineers must make claims that rely on collected data as a means for justifying their design decision. This study examined how two groups of elementary students engaged with this specific practice (i.e., using data to support design decisions) by investigating the justifications for their espoused design decisions during an engineering design challenge. Using discourse analysis methods, this ethnographic microanalysis examined the ways in which students legitimized their design choices, in addition to investigating how those justifications were or were not validated by the classroom teacher. Findings indicated students used either their personal authority, or the data and expert authority it provided to support their engineering design decisions. Additionally, the classroom teacher mostly validated student justifications constructed using applicable sources of data while providing few opportunities for students to enact their personal authority. Findings highlight the need for instruction that purposefully connects students' personal authority with specific aspects of the design problem space so students can feel empowered to pursue and test the validity of their initial design ideas using applicable data.

Introduction

Up until the release of the Next Generation Science Standards [NGSS], engineering education received minimal attention in K-12 classrooms in the United States (National Research Council [NRC], 2009). The NGSS are built upon *The Framework for K-12 Science Education* (NRC, 2012), which explicitly integrates science and engineering, something previously done in just 12 states in the United States (Carr, Bennett, & Strobel, 2012). Globally, engineering education has continued to make progress in formal institutions such as schools because it can impact career choice (e.g., Capobianco & French, 2014) and increase student achievement (e.g., Carson & Sullivan, 2004). Learning experiences highlighted by engineering design harness students' curiosity by providing authentic, design-based, cooperative learning experiences (Brophy, Klien, Portsmore, & Rogers, 2008; NAE & NRC, 2014; National Science Foundation, 2010; Moore et al., 2015) that culminate with an engaging *engineering design challenge* (Samuel, 1986). Engineering education will continue to have an emerging presence in classrooms across the world (International Technology Education Association, 2000), particularly in the United States with multiple national reform documents (e.g., National Academy of Engineering [NAE] & NRC, 2009; 2014; NRC, 2012) now justifying the necessity of its inclusions because of economic and/or national security interests (Hanushek, Jamison, Jamison, & Woessmann, 2008; NAE & NRC, 2007; Roschelle, Bakia, Toyama, & Patton, 2011).

In the United States, 18 states have now adopted the NGSS (Moore et al., 2015). Teaching and learning in science classrooms must now include *engineering practices* and encompass aspects of *engineering design*, which have risen to the same level as scientific inquiry (NGSS Lead States, 2013). Teachers and students alike may be unfamiliar with learning environments driven by engineering design (Brophy, 2008). Engineering-focused learning experiences will require students to engage in new processes and procedures while thinking and talking in ways that differ from their accustomed method of communication (Lemke, 1990). As the field continues to search for evidence teachers can provide "expert guidance" (Mercer et al., 2004) during engineering-based learning experiences.

Research Rationale

Research inside actual elementary classrooms is of interest because most studies to date merely explore engineering in K-12 classrooms by measuring student and/or teacher attitudes (Diaz & Cox, 2012). Studies that investigate how teachers navigate, and students negotiate, their understandings of engineering practices are emerging yet limited (Honey, Pearson, & Schweingruber, 2014; Kelley, Capobianco, & Kauf, 2015). Advocating for elementary students to "think and talk" in a manner similar to practicing engineers motivated the current study because too often classroom teachers "demonstrate a set of complex and subtle skills and expect students to figure out how we do it" (Lemke, 1990; p. 22). The *process of design*, a key component of engineering that relies heavily on collaboration and language use, posits that students should "learn the core elements of engineering design processes and have the opportunity to apply those processes completely in realistic situations" (Moore et al., 2014, p. 5). The ways in which students choose to engage in the design process may not be privileged because too often schools privilege unfamiliar language patterns and norms without considering the ways various discourses and literacies can be strategically integrated and leveraged within schools (Anderson, 2007). For example, science represents a particularly challenging environment for students because it contains, "unique discursive conventions and particular assumptions about what counts as knowledge" (Moje et al., 2001, p. 41). This tends to result in activities being "structured hierarchically with the teacher and the text controlling what knowledge counts" (Barton & Yang, 2000, p. 875). Classroom environments aligned to the NGSS need to promote practices (science and engineering) that utilize students' diverse cultural assets as a benefit to themselves and their own learning (NRC, 2012).

As elementary-aged students begin to take on and enact practices similar to that of real-world engineers, studies should continue to explore how they engage in the engineering design process (Brown, 2017), especially given that students likely lack directly relatable experiences with engineering design. Students tend to draw on and bring in related experiences to the design problem space, as professional engineers often do (Crismond & Adams, 2012); however, these experiences may or may not be successfully brought into the experience without well-structured, reflective instruction (Wendell, Wright, & Paugh, 2017). Engineers commonly engage in this reflective action because quite often their personal experiences help them bring in relevant perspectives to the design problem space (Cross, 2003). To successfully bring new learners into the world of engineering, we will need students to believe they can develop personally meaningful and "powerful" ways of knowing (Cunningham & Kelly, 2017, p. 501), which can only be accomplished via authentic "engagement in the practices of an epistemic culture" (p. 501).

This study explores the actions and discourse patterns of one elementary science teacher and two groups of fifth grade students during an engineering design challenge. The current study was guided by the following research question: *In what ways do two groups of elementary students vocalize and justify their engineering design choices while designing a prototype "survival suit," and in what ways are their design choices validated by their classroom teacher?*

Literature Review

Challenges Associated with Engineering in Elementary Education Settings

Teachers will undoubtedly face challenges as they begin to articulate and enact the practices of engineers with their students in science classrooms just as they have with scientific inquiry (e.g., Zhai & Tan, 2015) and scientific argumentation (e.g., Martin & Hand, 2009). Integrating engineering into elementary classrooms can particularly be difficult for teachers because many have limited pre-service education in engineering education and limited experiences with engineering-specific practices and are developing new pedagogical strategies to facilitate open-ended, collaborative learning experiences (Yu, Luo, Sun, & Strobel, 2012; Lachapelle & Cunningham, 2014). Engaging students in authentic engineering contexts affords them the opportunity to learn "firsthand how engineers solve problems, work in teams, and use science and mathematics" (Capobianco, Yu, & French, 2014, p. 288). As teachers facilitate these types of opportunities with their students, they must become "comfortable with the uncertainties inherent in student-centered investigations" (Lesseig et al., 2016, p. 182). To promote these investigations, teachers must afford students with access and practice using language associate with engineering (Mangiante & Moore, 2015).

Collaborative efforts wherein teachers and students take on novel, open-ended engineering design challenges via conjoined discourse are an emerging phenomenon in science classrooms (Lachapelle & Cunningham, 2014; Yu et al., 2012). Teachers may not necessarily be prepared to structure and guide these endeavors because the process of design is often portrayed as being a step-by-step process. When students experience the design process in a linear fashion, the iterative nature of the process is lost and they are not allowed to see how scientific ideas can be utilized during troubleshooting situations (Crismond & Adams, 2012). Student activity during open-ended design challenges can be chaotic and prompt teachers to ask close-ended, simplistic questions in an attempt to exercise control over their student's action (Reinsvold & Cochran, 2011), which in turn limits the likelihood students will use their everyday discourses and apply personally-relevant, experience-based ideas during challenges of this nature (Brown, Reveles, & Kelly, 2005). This is unfortunate because students could instinctively bring pertinent knowledge about the natural world with them during open-ended design challenges if they feel and know these ideas are valued (Lemke, 1990; Mercer, 1995). Discipline-specific language practices can be particularly challenging for students because they include specialized literacy skills, a high volume of content-specific vocabulary, and unique ways of describing and explaining ideas and concepts (Gee, 2008; Zwiers, 2014). To overcome these supposed challenges, instruction tends to emphasize content-specific vocabulary (Carrier, 2017), without recognition of how students will *use* language to participate with that content (Bigelow et al., 2006; Fortune et al., 2008). This often occurs because it is difficult to identify the language students will need and be using (Lucero, 2012, Schleppegrell, 2004) especially when unfamiliar disciplinary knowledge and discourse practices are featured and needed. Lemke (1990) highlighted how infrequent teacher-student dialogue included "meta-discourse," or "talk about talk," noting that:

> little classroom dialogue is devoted to the exposition of the patterns, to explicitly telling students just what the relationships of key terms are and how those relationships fit together into a larger pattern. Most of the time the patterns are simply there *implicitly.* They are assumed, presupposed, made use of. But rarely are they shown and explained directly. (p. 22)

Helping teachers learn the importance of articulating to their students how implicit mechanisms undergird the knowledge generation process for a particular discipline will be important, especially given the relative newness of widespread pre-college engineering education (Cunningham & Carlsen, 2014). Failure to provide this type of support for students will leave many without a realistic entry into the world of open-ended, ambiguous engineering design challenges, which are heavily reliant on communication and collaboration (International Technology Education Association, 2000).

Theoretical Framework

Epistemic Practice of Engineering

Engineers engage in discipline-specific work, which entails distinct epistemic practices that contribute to the ways useful knowledge gets generated (Bucciarelli, 1994). Engineering differs from science because engineers typically encounter ill-structured design problems. Design problems "possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, (and) unanticipated problems" (Jonassen, 2010, p. 7). Because of this challenge, engineers commonly solve design problems in teams, which in turn requires effective communication skills (Bucciarelli, 1994). More specifically, engineers need to "deal with ambiguity and complexity" (Jonassen, Stroebel, & Lee, 2006, p. 146) when talking with clients, working with peers, and presenting their work. It is precisely because the design process brings together individuals from varying backgrounds that engineers must "join together to plan, decide, critique, and integrate their efforts" (Bucciarelli, 1994, p. 110). Tensions will naturally arise in situations such as this, which in turn initiates the need for social negotiation. Novices with little to no understanding of the implicit mechanisms driving the discourse patterns being propagated will struggle to participate effectively and understand the knowledge generation process for that community (Cunningham & Kelly, 2017).

Science and engineering, while containing similarities, vary fundamentally in terms of epistemological features. Engineering is not merely an application of science; rather it has its own methods for constructing necessary and needed knowledge (Bucciarelli, 1994). Scientists focus on generating new and verifiable knowledge, while engineers tend to search for solutions to identified problems (Cross, 2003). *Data*, as a form of evidence for making claims (in science) or designing solutions (in engineering), play a critical role during both a scientific pursuit (McNeil & Berland, 2017) and any given engineering design cycle (Cunningham & Kelly, 2017). Scientists utilize data to explain and validate observed patterns in the natural world via a socially accepted process (Duschl, 2000), while engineers utilize data as a means for assessing the performance of a designed solution against a set of criteria and constraints (Cross, 2003). For engineers, data are oftentimes over-generated via extensive "experimental parameter variation" (Vincenti, 1990) to compensate for a lack of theoretical and/or useful knowledge. Engineers therefore rely heavily on data as a means for justifying their designed solutions to meet a specific client's requests. This process of data generation and analysis typifies one of the major ways in which an engineer would enact a particular "epistemic practice" (Kelly, 2008, 2016). Recognizing the nuances of a sanctioned practice allows one to make "legitimized" knowledge, thereby avoiding repercussion and exclusion (Cunningham & Kelly, 2017).

Team Commitment via an Explanatory Inquiry

The sociocultural perspective adopted for this study recognizes that without language there is no science or engineering (Lemke, 1990) and that learning involves the negotiation of ideas via language (Bruner, 1990). Over time, via extended interaction members of a group negotiate meanings (Vygotsky, 1978) and develop distinct discourses (Gee, 2000) that determine the norms and expectations for action amongst the group (Kelly, 2014). When individuals engage in collaborative dialogue, as teams of engineers frequently do, they keep track of commitments agreed upon by the group, often implicitly (Keefer, Zeitz, & Resnick, 2000). From this perspective, dialogue becomes cooperative and would be considered a "socially distributed activity" (Keefer, Zeitz, & Resnick, 2000). Walton and Krabbe (1995) present a lens (*Contexts of Dialogue*) that further describes how members of a group move forward during what they label an "explanatory inquiry." During an explanatory inquiry, it is initially understood that there is a need for a specific type of knowledge that once acquired will move the group forward. Initially, it is possible for the premise of an argument or suggestion to be backed by "personal beliefs" (Keefer, Zeitz, & Resnick, 2000), something professional engineers frequently do (Cross, 2003). However, initial ideas need to be discussed as further evidence is generated. Ultimately, the group must take "cumulative steps" (Walton & Krabbe, 1995) as justifications are discussed and weighed against the available evidence. In the end, this process eventually should lead the group towards convergence on a single decision agreed upon by everyone.

Accountable Talk and Engineering Design

In line with the theoretical groundwork discussed above, students will need appropriate "scaffolding" to participate in "productive disciplinary engagement" (Engle & Conant, 2002) with one another via a variety of language representations (Novak, 1977). As certain meanings are negotiated, novices require ample support and the ability to explore preliminary ideas and explanations in a safe environment (Cazden, 2001). In line with this thinking, Mercer, Wegerif, and Dawes (1999) propose teachers explicitly lay the groundwork for "exploratory talk" (Mercer, 1995) wherein "*knowledge is made publicly accountable and reasoning is visible in the talk*" (Mercer, Wegerif, & Dawes, 1999, p. 97; emphasis in original). Whole-group reasoning and intellectual development (collective and individual) ensues once students understand the ways in which particular discourses can be used collectively (Mercer et al., 2004). In essence, the ultimate aim is for students to recognize they themselves are "stakeholders" to others inside the classroom (Engle & Conant, 2002). To keep students from catering to the teacher's interests and points of view (Lemke, 1990), students must come to realize the value of their own ideas and be internally persuaded to use privileged discourse practices valued by the community.

Tensions between Legitimizations

Students who engage in an engineering design challenge without the necessary language supports (e.g., Engle & Conant, 2002) may experience tension when competing discourses emerge (Moje et al., 2001; Kittleson & Southerland, 2004) as they propose plausible solutions to the problem at hand. As described above, students (engaged in the epistemic practices of professional engineering) are going to have to use data to support their reasoning and justification for the specific design choices they make. Implicit within this process is the expert authority privileged (van Leeuwen, 2007) to decisions informed by the data. It therefore becomes vitally important for novice learners to understand that data-informed decisions undergird the process by which engineers generate new knowledge. Without this understanding, and especially when a design challenge includes an engaging, real-world context that utilizes familiar materials (Moore et al., 2014), inevitably students will bring their personal experiences and ideas into the situation. The ways in which students and teachers balance this tension between discourses, and where they place and endorse positional authority, therefore should influence the justifications students provide when describing their designed products.

Van Leeuwen (2007) presents a framework for analyzing the ways in which knowledge gets legitimized through discourse, by examining the questions of *Why should we do this?* and *Why should we do this in this way?* According to van Leeuwen (2007), legitimations take up one of four forms. Each form (e.g., *rationalization*) legitimizes knowledge by invoking specific language features and discourses (van Leeuwen, 2008). The current study was concerned with legitimation via *authorization*, which is further subdivided into personal authority, expert authority, role model authority, and impersonal authority (van Leeuwen, 2007). Personal authorizations offer legitimacy through personal status, whereas expert authorizations do so via the expertise someone brings to a situation. When the example of an expert is mimicked, role model authorization is being enacted. Finally, impersonal authorizations provide legitimacy by following rules, laws, or regulations (van Leeuwen, 2007). By examining student discourse for patterns of legitimation, we sought to explore how students went about solving the problem of "why" and "how" (van Leeuwen, 2008) when justifying their design decisions.

Research Design

The current study, an ethnographic microanalysis (Erickson, 1992), included classroom data from a single fifth grade classroom collected over 10 consecutive days. The teacher of interest, Mr. Mills (all names are pseudonyms), was purposefully selected and identified as being "information-rich" (Patton, 2002) because of his self-identified interest in developing student-to-student dialogue and his past experiences implementing *Engineering is Elementary* (*http://www.eie.org/)* in his classroom. Mr. Mills' role as a science specialist was also taken into consideration during participant selection, because these positions are becoming increasingly influential in elementary schools (Marco-Bujosa & Levy, 2016). At the time of the study, he had five years of teaching experience and held dual licenses in elementary education and grades 5-8 science.

Setting and Participants

Mr. Mills participated in a professional development experience that asked teachers in grades 4-8 to bring integrated STEM education to their elementary science classrooms prior to the 2014-15 academic year. As part of this project, 40 teachers from diverse schools within a large, Midwest metropolitan area in the United States worked in teams to develop a STEM-integrated curriculum that aligned with the state's science and engineering standards. Mr. Mills and a colleague worked with the first author for three weeks over the course of the summer to develop the curriculum highlighted in this study.

Specifics of the Unit

During the unit students needed to design a survival suit for a specific environment or biome (e.g., rainforest). Students needed to develop and apply their understanding of how animal adaptations can help animals survive in a given environment as they made design choices for specific components of a hypothetical, prototype survival suit. Prior to the culminating engineering design challenge, students conducted various tests of the "adaptive attachment options" that would become a part of their survival suit at specific stations. Survival suits contained four components: suit material, suit color pattern, food gathering attachment, and a movement/foot attachment. Ultimately, students needed to analyze, interpret, and use the data collected from the testing to determine which attachments worked best for a given environment. For example, one station prompted students to test how heat transfer impacted different suit materials. Students conducted the test by using a laser thermometer to first take the temperature of a specific target on their lab bench. They then covered this point with the material and turned on a heat lamp placed one foot above the bench. After one minute, the lamp was turned off, the material removed, and students quickly recorded the temperature of the same target on the bench. This process was repeated twice more.

The setting for the implementation of Mr. Mill's unit is his fifth grade classroom. The school is a pre-K through grade 5, music-focused elementary school in a large urban school district. The demographics of the district are 31.4% Asian American, 29.6% African American, and 23.7% Caucasian American. Roughly one-third of all students are English Language Learners and 73% of students are eligible for free or reduced-price lunch. Students in the class worked in self-selected groups to complete the engineering design challenge. From the possible groups in the classroom, two target groups were selected for the focus of this research. Group 1 consisted of four female students—Swani, Tina, Molly and Ashley—while Group 2 consisted of four male students: Jack, Dylan, Aaron, and Mark. Selection of these groups was done in consultation with Mr. Mills to identify groups that would engage in significant conversation around the engineering design challenge and the choices they were making about the adaptive attachment options.

Data Collection and Analysis Strategies

Data Sources

As a participant observer (Patton, 2002) the first author collected the following pieces of data for ten consecutive class periods: field notes, classroom video, pictures of student actions, lesson plans that included student handouts and student work, and audio and/or video recordings of the target groups during small group activities. A camcorder was used to capture video of Mr. Mills at the opening and close of class. Additionally, a digital audio recorder was placed on the both target groups' tables to collect student-to-student dialogue during the middle of class. A camcorder was also placed at one student group's table as well. Initially, all video and audio were roughly transcribed, followed by a more detailed transcription using a combination of Jefferson transcription conventions (Majors, 2007) and those provided via Ochs (1979). These transcription conventions, which are included in the *supplementary materials*, were used to allow for the analysis of both what was said by students, as well as in what ways, to examine their use of discourse during the unit. Included in these conventions are markers for aspects of language such as, laughter, emphasis, intonation, pauses and rate of speech.

Analytical Approach

Data collected from the field initially were organized and analyzed by creating a content log for each respective day and dataset (i.e., whole class video and small group audio/video). Content logs contained time-stamped, incident-by-incident descriptions of all whole class and small group(s) data. Incidents and the associated descriptions allowed the data corpus to be catalogued for later use by marking "events" (e.g., transitioning from one design choice to the next) and "ethnographic chunks" (Jordan & Henderson, 1995) (e.g., examining a data table) that were further contextualized whilst referencing associated notes taken from the field. Finally, written researcher interpretations were created at this stage, with emphasis on describing the "dialectical, ecological relationships of mutual influence among participants in the event" (Erickson, 1992, p. 119).

To identify events for continued analysis, the corpus was explored for key exchange. To begin, events wherein participants needed to legitimize their design choices were located within the corpus. More specifically, it was of interest to discover instances wherein participants needed to discuss "the merits of the various ideas pertinent to the design goals" (NRC, 2013, p. 72) during an engineering design challenge. These merits were of particular interest because this examination afforded us the opportunity to gauge where students placed positional authority for their design choices. Additionally, it permitted extended analysis of the ways in which promoted discourse practices were conveyed and converted into action. Analysis continued by creating detailed transcriptions (Ochs, 1979) to better understand how and why different kinds of interactions could be experienced as "more or less educative" by two different groups of students (Erickson, 1992, p. 220). Field notes, classroom artifacts (e.g., lesson plans, classroom presentations, student handouts), and the transcript of a stimulated-recall interview were also consulted during this stage to provide contextual information about each situation (Lemke, 2012). During the stimulated-recall interview (Calderhead, 1981), Mr. Mills was provided with select audio and video clips from his classroom and asked a series of specific questions about each clip. Questions were generated while analyzing key exchanges from the corpus. Responses to these questions helped contextualize key findings revealed during data analysis (Calderhead, 1981). In total, 31 events and/or ethnographic chunks, lasting between 30 seconds and five minutes, all from days 7-9, were identified for continued analysis as a result of this analytical process.

To complete the final stage of microanalysis the entire data corpus, including the previously mentioned 31 events, was explored for analogous pairs of interaction to demonstrate the "representativeness" of the interactions to be presented (Erickson, 1992). In other words, this method of comparative analysis allowed the researchers to document and quantify the occurrence of similar instances spanning the entirety of the data collection period. Additionally, this search helped identify potential discrepant episodes. In searching for discrepant episodes, the researchers sought to provide evidence that disconfirming episodes were not "inadvertently ignored" (Erickson, 1992), but rather included within the data corpus. The efficiency of the aforementioned search coupled with the inclusion of disconfirming data strengthens the choice of exchanges selected for microanalysis and presentation. This method of comparison and analytical induction allowed for significant patterns of interaction to be generalized within and between student groups, while also enabling dimensions of contrast to be identified (Erickson, 1992). Finally, at this point in the analytical process, descriptions, analytical insights, and researcher interpretations were combined and/or used interchangeably (Wolcott, 1994).

Analysis concluded by using two discourse analysis tools from Gee (2010). First, Gee's (2010) *Activities Building* tool was used to investigate instances when one party attempted to get another to recognize the legitimacy of a particular practice. Typically, this was accomplished by focusing on the routinized nature and subsequent "rigidity" of the discourse practice being propagated. Participant actions that diverged from and/or attempted to deviate from the strictness of a particular practice were also of interest. Next, we employed the *Sign Systems and Knowledge Building* tool to explore how participants enacted varying sign systems, which in turn were taken as representations for how they portrayed "different ways of knowing the world" (Gee, 2010, p. 136). Finally (and as detailed in the theoretical framework above), van Leeuwen's (2007) notion of *legitimation* was leveraged analytically to examine how students justified and/or rationalized their design choices allowing for the identification of "where" students placed positional authority of their statements to justify specific design decisions.

Results

This section presents the findings from our analysis of the ways in which two groups of elementary students justified their engineering design decisions, and how their classroom teacher validated those choices. Our analysis revealed the two groups of students justified their engineering design choices in different ways, with Group 1 primarily enacting personal authority in support of their design choices and Group 2 primarily enacting design choices supported via the use of data. When examining the ways student design decisions were validated by the classroom teacher, we found the classroom teacher heavily privileged the use of data and provided limited space for personal authority in student justifications. Each of these three themes is expanded on and discussed in the sections that follow by providing description and analysis of key exchanges that illuminate how the data presented constitute the findings of each theme. Exchanges deemed *representative* are listed sequentially (i.e., *Extract*) and include the *Instance Number* listed in its originating table. Each data table also includes further contextual details (i.e., media type, time). Again, the study's key data sources (i.e., analogous or

Table 1. Enacting personal beliefs: analogous pairs and discrepant episodes

Instance Number	Media Type and Context (Whole Class [WC]/Small Group [SG])	Day (Approximate Length of Media)	Brief Description
<u>*Analogous Pairs*</u>			
5*	Audio (SG #1)	7 (2 minutes)	Group determines the best choice to keep warm is fur because of a trip she took to the mountains and needed to wear a fur coat to stay warm.
7	Audio (SG #1)	7 (2 minutes)	Author 1 probes the students about picking fur for their survival suit. The group initially states they made this choice because one of them has a coat with fur around the hood.
16*	Audio (SG #1)	8 (3 minutes)	The group is trying to determine which color suit they should pick to survive in the mountains. They pick orange/black ("tiger print") so suits stand out.
23	Video (SG #1)	9 (2 minute)	While completing the handout, two girls who were previously absent demand Swani and Tina give them a justification for choosing silver as the color of their survival suit. The pair struggle to come up with a reason, ultimately choosing blue and pink because they go together.
<u>*Discrepant Episode*</u>			
9*	Audio (SG #1)	7 (3 minutes)	The group is discussing food-gathering adaptations while implicitly considering how many food items each option picked up.

*Denotes representative instances further described in results.

"comparable" pairs) are presented by first providing background information about the design activity the students and Mr. Mills were engaged in during that episode, followed by a description of the episode and analysis of the findings related to the theme for that episode. Additionally, within each one discrepant episode is highlighted to illuminate how the groups of students at times used varying resources to justify their engineering design choices. Finally, one discrepant or "contrasting" episode is detailed that demonstrates how at times Mr. Mills' actions did not align with the other episodes displayed in the study's final theme.

Theme 1: Enacting Personal Authority to Support Their Design Choices

Group 1 relied primarily on their personal authority to support their engineering design choices. Table 1 provides an overview of the analogous pairs for this particular theme along with a single discrepant episode that contrasts with the theme presented.

Analogous Pairs

The conversations Group 1 engaged in focused heavily on the use of personal authority to justify their design decisions. This personal authority encompassed the students' personal experiences, as well as personal preferences, both of which were used by the students to inform their design choices. The next two conversations display how Tina and Swani used their personal authority while participating in the engineering design challenge. The first of these conversations occurred on day seven of the unit. This lesson began with Mr. Mills describing how students would use the engineering design process to create a survival suit (further described in *Theme 3*).

Extract 1 – *Instance #5*

Swani	so I was thinking we pick fur
Tina	fur indented
T&S	((reading off data table)) The material was punctured and the tack went all the tack way through the material
Tina	so/ (.) ( ) (.)
Swani	I think <u>fur</u> is better than↓/
Tina	than the leather (.) yeah fur (.) in this one the fur is still ( ) I would choose fur because it ke/ it keeps you warm by the fur
Swani	yeah because this is like a mountain and there's snow up here and here's/
Tina	yeah
Swani	well because <when I went to Yellowstone> it was um/ up in a mountain/ cause we drove a car]
Tina	// it was cold]
Swani	it was cold and it was really cold so: (.) um so I think fur is good
Tina	fur: keeps you <u>warm:</u> and (I think that its spring) or probably in the summer but mountain isn't/ it <u>is</u> (rainy) but we're in the winter (that)
Swani	when I went to the mountain (.) like it's really cold because we drove up and then we went and we parked our car and then we uh there's like snow up there and I touched it (.) it was really cold up there so
Tina	wait wait wait if you look here ↑ : (.) it's like super hot but if you look up here it's <u>really</u> cold ((referencing a picture))
Swani	Just like in real life
Tina	h- mountains is um colder <because it's> up way in the sky ↓
Swani	yeah its higher than the (grass) normal sand (.) and: um-WHAT ABOUT THE SCALE
Tina	SCALES not gonna <u>WORK</u>
Swani	why ↓
Tina	You kidding me↑ @,@
Swani	um: feathers ↑ or fur ↓
Tina	fur
Swani	yeah let's choose fur <because it will keep you warm in the mountains> you know and fur keeps you warm in the mountain

Additionally, Mr. Mills prompted students to use the information in the data tables he compiled when making justifications for a given design choice. Following this whole class instruction, Tina and Swani began discussing possible the available adaptive attachment options for their survival suit. In the extract below (Extract 1), Swani and Tina returned to their table following Mr. Mills' instruction and worked together to determine what material they should use to keep warm in the mountainous environment they had been assigned. Swani and Tina worked closely with each other during the classes leading up to this point and were examining a handout Mr. Mills asked them to complete (see supplementary materials for transcription conventions).

Swani and Tina began (lines 1-8) by clearly identifying fur as the obvious choice despite Tina's brief interjection this material "indented" or flexed during the puncture test (line 2). Swani recently visited a mountainous environment, and therefore felt she could use this experience to help with the choice they needed to make (line 11-19). She noted that in addition to driving to the park in the mountains, she got out of the vehicle and actually "touched" the snow (line 19). After referencing an image that depicted a mountain (lines 21, 22) and noting that "just like in real life" (line 21) it gets colder as you move up a mountain, Tina wondered if scales might work (lines 23, 24). Swani emphatically stated scales would not work (line 26) and ignored Tina's final suggestion the duo consider feathers (line 29). Swani and Tina eventually agreed fur was the best choice, solely based on Swani's experience in the mountains. The handout students had access to also contained numerical data that indicated fur as the best option; however this information was not relied on here to help the group make a determination.

In this example, the students directly relied upon their personal authority to support their design choices, particularly Swani. Tina started by noting that the fur will "keep you warm" but did not provide any data to support this claim, instead presenting it as just a given. Swani built on this idea by drawing on her experience traveling to Yellowstone National Park, and driving up on a mountain. This personal experience helped her decide which adaptive attachment option to pick because she knew it was cold in the mountains and they would therefore need to stay warm to survive. In making these statements, Swani leveraged her "personal authority" (van Leeuwen, 2007), which is the authority "vested in a person because of their status or role in a particular institution" (p. 94). More specifically, she leveraged a personal experience outside of school Tina did not partake in to justify the selection of fur with Tina present. Van Leeuwen (2007) noted that personal authority often does not require more than a "because I say so" (p. 94) type statement, which is essentially what Swani did through both her initial presentation of fur as a choice and her dismissal of Tina's suggestion to consider the feathers and scales.

The next extract occurred during day eight of the unit. During this lesson, students continued to design their survival suit. In this conversation, two students who were absent from class on day seven, Molly and Ashley, joined Swani and Tina. Together the four students wanted to find out what color their survival suit should be, building on the work Swani and Tina had done the day before. The week prior, students participated in a content deepening lesson about camouflage. Briefly, they collected data that helped them understand how a material's coloring pattern could make it easier or harder to see in a given environment/background.

Extract 2 – *Instance #16*

1	Swani	we picked cheetah prints(.)
2	Molly	cheetah print (.)
3	Tina	((writing on worksheet)) we choose (.) cheetah (3.0) cheetah
4	Molly	cheetah print (.) no it was not cheetah print because it was not dots.
5	Tina	ah! tiger↑
6	Ashley	yeah tiger (.) it looks like a tiger↑
		((6 lines pass as students write on their worksheet))
12	Tina	((reading prompt from worksheet)) why did your group choose that coloring use=okay so we
13		want to be seen/
14	Swani	we want to be like pop=like pop out.
15	Tina	like pop like/
16	Swani	like we want to be seen/
17	Molly	it's called bright colors
18	Swani	yeah, whatever (.) it's another way (.) okay let's do it (7.0) hey Molly let's ask Ashley (.) ((readi
19		worksheet)) why did your group choose that color?
20	Tina	we choose because we want to be seen (.)
21	Molly	we want to be seen more ↑ then the animals will <u>come and eat us!</u>
22	Swani	no so the animals won't eat us and we will eat that that animal/
23	Tina	I don't think they'll come eat us because we're like ((incomprehensible)) if were a human
24	Molly	because it pops out and (.) um it's bright (.) It'll be bright in the snow↑

During day seven, Swani and Tina colored their survival suit. Swani began this conversation by describing how they decided their survival suit should have a cheetah print design (line 1), which Molly then clarified (line 4). Tina and Ashley then corrected Swani to say it looked like a tiger (lines 5-6). After a few exchanges passed while the students wrote the words “orange” and “black” on their design sheet, Tina read the next question: “Why did your group choose that coloring?” (line 12). Swani stated they wanted to pop out (line 13) and that they wanted to be seen (line 15). Molly provided another way of saying this, noting “It’s called bright colors” (line 16). Swani then asked Ashley to help with this question (lines 17-18). Ashley did not respond and Tina stated, “We choose because we want to be seen” (line 19). Molly challenged this idea by saying, “We want to be seen more? Then the animals will come and eat us” (line 20). Swani responded, noting that the animals will not eat them and instead they will eat the animals (line 21), to which Tina agreed (line 22). Molly decided to go along with the group, noting this choice makes sense because it will “pop out” and be bright in the snow (line 23).

Similar to the previous extract, students did not draw on the data they had previously collected to make their design choices. In this example as in others, they provided justifications for why they thought the suit should be colored orange and black, like a tiger, such as “because we want to be seen” and “it pops out.” However, these justifications were not supported via the use of data from the materials testing they all completed before and were prompted to do so early today. Instead, they scanned a provided image of the mountain environment they needed to survive in and felt it would be important to “pop out,” something they likely picked up for the previous lesson about camouflage. Notably, they made no reference to this lesson or the tests they conducted when making this choice. Instead, they inferred that if they could be seen it would enable them to capture more prey, a likely misconception (Allen, 2006). During his stimulated-recall interview, we asked Mr. Mills to analyze an exchange similar to this one. He stated that in his career he commonly saw students “overriding” the information he’d provide with their personal experiences because they are kids and “that’s what they’re going to do.” He also felt that kids in particular, more so than “science-minded adults,” find it harder to let go of personal experiences in the classroom and that it was his job to further “probe” their thinking to better understand what he could do to meet them where they were at.

Discrepant Episode

While Swani and Tina, and to a lesser extent Ashley and Molly, relied on personal authority and a common misconception (Allen, 2006) to justify their engineering design choices, we uncovered one instance wherein they utilized a data source to justify a design choice. In this exchange, Swani and Tina needed to respond to a written prompt on their survival suit design sheet that asked them to choose which food gathering adaptive attachment option to pick. Within the prompt, they were also explicitly asked to explain why they picked the option they did and to describe the data source they used to help them make that choice.

Extract 3 – *Instance #9*

1	Swani	which food gathering adaptive attachment did you group choose for your suit ((reading the
2	Tina	prompt))
3	Swani	clear mouth
4		why did your group choose that adaptive option (reading the prompt) (…) use your data and your
5	Tina	knowledge of/ (mumbles) ((reading the prompt)) what is this part
6	Swani	( )
7	Tina	its what/
8		I picked that adaptive attachment because/ I picked it cause it picked up the food <u>with the mouth</u>
9		(3 turns pass)
10	Swani	let’s just ( ) because it gets <u>more</u>: ° ° it gets more ° ° (..) choose that one up here
11		(5 turns pass)
12	Swani	we choose the uh: clear mouth because it gets more (food) when we were picking it up
13		(5 turns; 45 seconds pass while they write their response)
14	Tina	you spelled because wrong
15	Swani	because it picked more food up

Swani began by reading the prompt from the survival suit design sheet (lines 1-3). While she was reading, Tina interjected with the statement “clear mouth” (line 2), apparently suggesting they should choose the clear mouth for the food gathering adaptive attachment option. After reading the prompt, Tina provided a rationale for picking the “clear mouth” (line 7, 8). After three turns passed, Swani built on Tina’s idea by implicitly bring a piece of information they gathered earlier in the unit. She suggested they should choose this option because “it gets more” (line 10). Swani indicated her implicit agreement with Swani (Keefer, Zeitz, & Resnick, 2000) by quickly copying down her response, saying, “we choose the clear mouth because it gets more [food] when we were picking it up” (line 12). This exchange contrasted with the others in Table 1 because Swani and Tina implicitly drew on the “expert authority” (van Leeuwen, 2007) the data provided even though their actions were prompted by design sheet in front of them.

Theme 1 Summary

Upon reflection, it is worth considering that Mr. Mills still found it somewhat burdensome that his students frequently used personal experiences to justify their design choices, even though professional engineers often do this, particularly when starting the design process (Crismond & Adams, 2012; Cross, 2003). Because their teacher did not recognize the role of this characteristic strategy of professional engineers, it was highly unlikely Tina or Swani felt invoking their personal authority (van Leeuwen, 2007) within the design problem space (Jonassen, Stroebel, & Lee, 2006) was necessary or valued. In Tina’s case (*Extract 1*), a design decision was made because of an experience she did not and could not partake in.

Table 2. Using the data to support their design choices: Analogous pairs and discrepant episodes

Instance Number	Media Type and Context (Whole Class [WC]/Small Group [SG])	Day (Approximate Length of Media)	Brief Description
<u>*Analogous Pairs*</u>			
10	Video (SG #2)	7 (2 minutes)	The group begins thinking about and discussing how they can use the data to decide which suit material to use. With Mr. Mills listening in, they discuss how much certain materials flexed while looking at the data table.
12	Audio (SG #2)	7 (2 minute)	The group is considering foot adaption options and is discussing how the data in front of them can help them determine which option is the best.
19*	Audio (SG #2)	8 (1 minute)	One student in the group has picked up on how to use the difference in measurements for the puncture test and informs a classmate how to do this.
26	Audio (SG #2)	9 (1 minute)	Students in the group are excitedly reading of the numbers from the food gathering test in defense of which food gather option they should pick.
27*	Audio (SG #2)	9 (2 minutes)	The group is still discussing which food adaptive option to pick. They shout out to each other and disagree at times about who wrote what on the handout.
28	Audio (SG #2)	9 (1 minute)	The group continued to use the data to discuss food adaption options and called Mr. Mills over to tell him they were having a “debate.”
29	Audio (SG #2)	9 (2 minutes)	Author 1 asks the group about their decision to pick amphibian skin and they tell him it was the second strongest. They note Mr. Mills wants them to indicate how far it stretched.
30	Audio (SG #2)	9 (1 minute)	The group notes that “they are not playing around” as they finalized their decision to use amphibian skin because it stretches 5cm more than leather.
<u>*Discrepant episodes*</u>			
11*	Audio (SG #2)	7 (3 minutes)	The group is discussing how many items each food adaptive option picked up using the data, but ultimately decide to make their decision by playing a game.
13	Audio (SG #2)	7 (4 minutes)	The students decide to pick certain colors based on the colors they think will be able to hide them in a specific environment.

*Denotes representative instances that are described further.

Additionally, in the second extract, the group retrospectively justified a design choice (i.e., suit color) based on logical reasoning (i.e., we will be seen with bright colors), but unfortunately counter to the conceptual understanding animals typically blend in to their surroundings, not stand out. Neither situation detailed above could be considered ideal, but by examining the ways in which students invoked their personal authority when moving towards a desired endpoint (i.e., an "explanatory inquiry"; Walton & Krabbe, 1995), it can expand our understanding of the convoluted problem space elementary-aged students will create when they bring in relevant person experiences while solving an engineering design problem.

Theme 2: Using the Data to Support Their Design Choices

In contrast to Group 1, Group 2 regularly invoked the positional authority of the data when justifying their design choices by explicitly referencing it within their verbal descriptions for why a specific adaptive attachment options should be selected. Table 2 overviews the analogous pairs and discrepant episodes identified via the analysis of group conversations. Only three of the instances below were selected for continued microanalysis. Again, the last two instances described were labeled contrasting or "discrepant" due to the way students justified their design choices.

Analogous Pairs

Group 2 regularly discussed the data when trying collectively to come to a consensus about a design decision. During this first exchange (*Extract 4*), students were involved in the second lesson dealing with the design of their survival suit. Below, they were specifically focused on selecting the material from which their suit would be fabricated. Prior to this lesson, students conducted a "stretch test" to essentially determine the elasticity and strength of a given material under a set amount of force. As Group 1 did, Group 2 also worked on a survival suit design sheet while they discussed their options.

Extract 4 –*Instance #19*

1	Jack	I don't get it: ↑ (.) at all (.) I need help ↑
2	Aaron	he [Mr. M.] wants to know how many h/how much it went up one centimeter
3	Jack	<HOW DID IT GO UP BY ONE CENTIMETER?>
4	Aaron	he wants to know the two total by leather <u>and</u> amphibian skin so:/ // ( )]
5	Dylan	// yeah it might (mean) uh:]
6	Aaron	like pretend if=if amb/ if amphibian skin was like 3 centimeters but/ leather
7		skin is two/ two point nine
8	Jack	@ I just wrote the/ two point nine
9	Aaron	yeah=but it says two point five but that went up fiv/ fiv/ five centimeters not
10		one centimeter=I got hiccups
11	Jack	OH! I GET IT=I GET IT=YEAH!
12	Aaron	you get what I'm saying ↑
13	Jack	// <yeah, yeah, yeah>/ ( )]

Jack began by voicing his confusion (line 1). Aaron followed, noting that Mr. Mills ("he," line 2) needed a number indicating the results of the stretch test. Jack laughingly stated he just wrote down the final value of the test (line 8), which Aaron clarified by presenting an example using amphibian skin (lines 6-7). Aaron accomplished this by telling Jack that what needed to be recorded was the difference (line 10), not the ending data point. Aaron realized that a tenth of a centimeter difference between two options (i.e., 2.9 cm and 3 cm) could make the difference when justifying the selection of one material type over another; this further reinforces his recognition that engineers rely heavily on data when analyzing the performance of a given test (Cross, 2003). Given this exchange we cannot decipher if Aaron believed the data he analyzed could tell him which option to choose or if he emphasized this method because Mr. Mills strongly privileged the use of data when making design decisions (Barton & Yang, 2000). This will be described further in the study's final theme.

In the next extract, students were redesigning their survival suit. In brief, students now needed to design a suit that worked in both a prairie environment and their original environment because an unforeseen shift in the unit's context. Prior to this lesson, students completed a "food gathering test" using plastic hair clips of varying sizes to collect a variety of "food" sources; represented via large seeds and two different-sized plastic beads. Students essentially needed to decide which prototype "mouth" would help them collect the predominant food type of a specific environment. A female aide paired with the group also intervened in the below discussion. As seen below, she wanted students to use a data sheet that listed “mouth type” and the “amount of food picked up.” Recall that Mr. Mills created this table and had previously informed students the data came from the materials tests they previously had completed.

Extract 5 – *Instance #27*

1	Jack	//wait which] one picked up the most big food ↑
2	Dylan	the red one/
3	Aaron	look in=look in the data
4	Dylan	look at the data look at the data
5	Aaron	<look at the data table>
6	Jack	so the white=no the seeds were the biggest/
7	Dylan	oh twenty-one
8	Aaron	twenty-one (..)
9	Dylan	twenty-one twice
10	Aaron	pink hair clip twenty four seeds ↑
11	Jack	but look at (.) clear ↑ FIFTY-FIVE COLORED BEADS ↑
12	Dylan	ooo:
13	Jack	but those are small:
14		(19 turns pass, an aide enters wanting to ensure everyone is involved in the discussion)
15	Jack	yeah because were trying to figure out which one picks up more
16		(11 turns pass, the aide wants to know why they changed their answer on the handout)
17	Jack	cause ↑ for prairie prairie has big food like gazelle and uh um pink hair clip um it had uh
18		seeds are the biggest food on here and it picked up 24 of them
19		(8 turns pass, the team is split 2-2, one student suggests they fight to decide which to chose)
20	aide	no: you gotta base it on your data
21	Jack	see look at this you see how bad/ red clip/ yeah look red clip got twenty-one for the biggest
22		food and pink clip got twenty-four for the biggest food/
23	aide	I would use the thing that overall picked up the most and which is that
24		(6 turns pass, the aid suggests there are bugs in the prairie to eat)
25	Jack	why why would you be eating bugs you would be eating a gazelle:
26		can I tell you guys something (.) if there is big food in there then why won’t we choose the
27	Mark	biggest thing in there and see how/
28	Jack	that’s what I just/

Jack started off by asking which mouth type picked up the “most big food” (line 1), which everyone remembered was the seeds. As the others looked through the data table for the largest number of seeds gathered (lines 2-10), Jack decided to find out which option picked up the most amount of food, eventually discovering that the clear beak option picked up “55 colored beads” (line 11). His excitement was short lived because he soon realized the colored beads were too small and that the group wanted to collect large prey to each in the prairie (line 13). The aide entered at this point to ensure all members of the group were contributing, which Jack quickly reiterated they were (line 15).

The aide wanted to know how and why the group decided to change one of their design decisions (line 16). Jack made an insightful connection to the environment by bringing up the food type they wanted to catch was a gazelle, which was big (lines 17-18). The team conducted a simple vote at this point, only to realize they were split two to two. One student jokingly suggested they fight to solve the problem while another noted a game would suffice. The aide eventually suggested the group just pick the option that picked up the most food. This suggestion however, unfortunately missed the point the two students were trying to make about the size of the food they would be gathering in the prairie (lines 26-28), which would likely be large like the seeds from the simulation and test they conducted.

In this exchange, the group clearly relied on the expert authority of the data when discussing and coming to consensus on a decision. Even though they never reached a set end point, this conversation depicts how students quickly intertwined complex biological concepts in with their reasoning when immersed in a design problem space. Additionally, this exchange evidenced a group of students who knew they possessed valuable ways of knowing (Cunningham & Kelly, 2017, by enacting the roles of professional engineers discussing pertinent performance data in a specific and appropriate manner. Jack’s statement in lines 21 through 22 depicts how he understood the valued importance of backing his design choice with relevant data.

Discrepant Episode

And while Group 2 primarily used the data when making their design choices, there were a couple of instances where they used other means to inform their decisions. In the exchange below (*Extract 6*), they were again discussing which mouth type to pick. Five minutes prior to this exchange, students had just been introduced to the unit's main engineering design challenge.

Extract 6 – *Instance #11*

1	Jack	how about food gathering ↑
2	Aaron	what do you use that for↑
3	Jack	// ↓ the food gathering adaption ↓]
4	Dylan	// I don't wanna/ I don't/] those things are stupid how are we gonna have hands like that when
5		we have hands like these: so we can grab any any/ everything // it looks like its]
6	Jack	// make a hand like this]
7	Aaron	//it's like a/] like a claw in your hands. (..)
8	Dylan	wait member how I got thirty // one] [wait]
9	Jack	// lets] go lets go to the white beads lets go to the white // beads]
10	Dylan	// wait] member how I got thirty-one (paper shuffling)
11	Jack	lets go to the beads stuff
12	Aaron	yeah: that's //the pick up] stuff
13	Dylan	//where is that] member how I got thirty-one
14	Jack	yeah:
15	Dylan	<what paper clip was that>= or what thing was that with (.) oh wait read the food first
16	Aaron	where's the food↑ (.) where's food!
17	Dylan	whoa:!
18	Mark	colored beans too
19	Jack	oh <we're gonna get the clear one>
20	Aaron	oh thirty-one's right here red
21	Dylan	oh yeah there's mine:
22	Jack	thirty one but fifty-five beads for colored // beads]
23	Dylan	// yeah but] uh what kind of food do we have=<is it big food or small↑ food>
24		(3.0)
25	Mark	big food: (.) that's big food:
26	Dylan	OH YEAH cause it's a:/ they said like mountain goats
27	Jack	yeah // wolf]
28	Dylan	// yeah] so that's big food so I'm thinking
29	Jack	thinking the highest one is for seeds
30	Dylan	and the/
31	Jack	seeds are↑ the biggest
32	Aaron	no white beads:
33	Dylan	yeah white beads are the biggest so uh=
34	Mark	=white beads and sun seeds
35		(4 turns pass)
36	Mark	oh yeah its cuz its even harder to clip, it's just like // (rrrr)]
37	Dylan	// its between] clear and red
38	Aaron	yeah:
39	Jack	its clear or red
40	Mark	which one should we choose? clear or red?
41	Aaron	// pink hair clip]
42	Dylan	// <Eeny meeny miny>] no rock paper scissors you have clear and I have red okay↑
43		(students start playing rock paper scissors, red wins two out of three)

The group orientated themselves with the task (lines 1-7) by referencing the prompt on their design sheet (line 1). Initially they did not know if they would be able to use their hands without the "beak clips," but eventually figured out the clips would be used "like a claw" (line 7). Dylan brought up the material testing they had conducted during the previous class (line 9), which refreshed the group's memory of the data they had collected to help them determine the clip to choose (lines 10-20). With the correct data table in front of them, they immediately looked for the two highest numbers, 31 and 55. Dylan pressed the group to do more than just look for the option that collected the most food items and suggested they consider the type and size of the food sources that would be available in their given environment (line 23) as they had done in the previous extract. The group hesitated to respond to this question, until Mark answered “big food” (line 25), which reminded

Table 3. Emphasizing the data

Instance Number	Media Type and Context (Whole Class [WC]/Small Group [SG])	Day (Approximate Length of Media)	Brief Description
Analogous Pairs			
1*	Video (WC)	7 (2 minutes)	Mr. Mills explains the engineering task and emphasizes how students need to be using the data to back their decisions.
2	Video (WC)	7 (1 minute)	Mr. Mills explains how students need to use the data to make decisions together as a group and settle disagreements.
3	Video (WC)	7 (45 seconds)	Author 1 tells the class that he and Mr. Mills do not know which adaptive options work best for any given survival suit. He describes how students should use the data to tell them which options would work best.
6*	Audio (SG #1)	7 (1 minute)	Mr. Mills stops by the group to tell them they need to be making their decisions based on the data. He notes their decisions cannot be based on what they remember. The group moves on to use the data briefly when trying to make a design decision.
7	Audio (SG #1)	7 (2 minutes)	Author 1 presses the group to use the data to justify their decision for fabric type. The girls read off the temperature readings from the data table (Figure 1).
8	Audio (SG #1)	7 (4 minutes)	Mr. Mills has an extended interaction with the group about their decision to use fur as the fabric type for their survival suit. Mr. Mills wants to know if the pair has data to support this decision, which they state they do not.
14*	Video (WC)	8 (2 minutes)	Mr. Mills confirms and clears up the confusion surrounding the data table. Students initially picked feathers as the fabric type because they did not realize an increase in temperature indicated heat loss. After clarifying this, Mr. Mills emphasizes how students need to use the data to back up their choices.
15	Video (WC)	8 (3 minutes)	Mr. Mills calls on a student to explain why fur is the best choice for a cold environment. The student states this is the best choice because the data table says so.
17	Audio (SG #2)	8 (1 minute)	Mr. Mills checks on the group’s progress with the handout they are completing. After reading their response to them, he indicates they need to use a measurement to justify the suit material they want to use for him to believe them.
18	Audio (SG #2)	8 (2 minutes)	This instances builds on the previous. Mr. Mills now approves of the group’s response to a question on the handout. He indicates he wants a bit more data indicating why leather is the best choice.
20	Video (WC)	9 (30 seconds)	At the beginning of the class, centered around redesign of their suits, students are now able to state back in unison that their design decisions need to be backed up by the data.
21	Video (WC)	9 (1 minute)	Mr. Mills clarifies that argumentation is not arguing and that arguments can be reinforced using the data.
Discrepant Episodes			
4	Video (WC)	7 (1 minute)	Author 1 poses a variety of questions for the class to consider when making their design decisions, all of which are focused around the tests students conducted by the previous class.
24	Video (SG #1)	9 (1 minute)	Author 1 asks the group about their color choice and lets their decision stand without asking them to provide data as evidence.
31*	Video (WC)	9 (1 minute)	Mr. Mills calls on a student to describe why her group changed suit color from orange/brown to blue/pink. Mr. Mills and the class are surprised by her response and no one brings up the data to justify the decision being contemplated.

*Denotes representative instances that are described further.

Dylan someone told him before that goats lived in the mountains (line 26). The group up to this point went from not knowing what adaptive attachment option to choose to now thinking they should choose the clip that best collected the largest food item (i.e., seeds) from the test the conducted earlier (lines 28-35). Dylan then stated they needed to decide between the clear and red clip, which both picked up 21 sunflower seeds (line 37). The group ultimately decided that they should play rock/paper/scissors to determine which option they should select (line 42). Even though this exchange contained similar student discussions, as seen previously from this group (e.g., *Extract 5*), we identified it as discrepant because when it came time for them to choose between two adaptive attachment options that yielded the exact same result, they decided to resort to the outcome of a game of chance to make their decision (line 42).

Theme 2 Summary

The students in Group 2 aligned their discourse practice with Mr. Mills' request to make data-informed decisions. They clearly understood engineering discourse practice involves assessing the performances of different design choices using data collected via a series of applicable tests. During the stimulated-recall interview Mr. Mills stated his appreciation for Group 2's display of data-driven discourse, noting they were having "a much better conversation as far as using the data goes" when comparing against what he had seen from group 1. During this interview, he also highlighted a curriculum design issue he had since addressed. Briefly put, he felt students were not provided with detailed information about each particular biome. This he felt hindered them from considering more specific constraints when making their design choices. However, as Jack evidenced (*extract 5*) he had been contemplating specific details of the biome, particularly the size of the food they would have available to them when hunting for prey. He mentioned this important detail as a counter argument to the aide's suggestion that the best option for food gathering would simply be the one that picked up the most food.

Theme 3: Data Emphasized by Mr. Mills through Instruction

When examining how students in both groups carried out their conversations and justified their design decisions during the engineering design challenge, it became evident that Mr. Mills validated both types of student justifications in different ways. Through our microanalysis we found he most often privileged students who referenced the previously collected data when justifying their design choices. This happened during both whole-class instruction and while he interacted with students in small groups. As will be detailed further below, he provided little space for students to use their personal authority as a means for justifying their design decisions. Table 3 provides an overview of the analogous pairs and discrepant episodes that accompany this final theme. The following section again begins by describing three instances wherein Mr. Mills emphasized data as the means for justifying design decisions. Finally, one contrasting episode is described that illuminates an alternative approach Mr. Mills enacted during the unit.

Analogous Pairs

Day seven of the unit began with Mr. Mills reminding students what had been accomplished during the previous class while also preparing them for the day's events. Ultimately, he wanted students to know there were multiple adaptive attachment options they needed to evaluate by using the data from previously conducted tests, one of which is further described below.

Since the class last met, he compiled and passed back the data from various "tests" students previously completed. Figure 1 contained data students previously collected via the "temperature test," which Mr. Mills had prepared for the class to analyze during today's lesson. During the test, students placed a variety of materials (e.g., feathers) under a heat lamp. From here, they were then supposed to use this information to determine which material type would keep them warm in a cool environment or vice versa. As seen in Figure 1, students had initially recorded the temperature of the surface "Before Heating," followed by repeated collection of the temperature in 5-minute increments.

Temperature	**Temperature of Fabric**			
	Before Heating	**5 minutes under the heat lamp**	**10 minutes under the heat lamp**	**15 minutes under the heat lamp**
Fabric #1 **Feather**	74.4	81.5	84.7	86.1
Fabric #2 **Fish Scales**	74.5	84.0	87.0	86.7
Fabric #3 **Leather**	77.4	84.0	83.1	84.0
Fabric #4 **Amphibian Skin**	75.0	83.8	84.0	84.1
Fabric #5 **Fur**	71.8	75.9	76.8	77.7

Figure 1. Example data table provided to students while making design decisions

In this exchange, Mr. Mills told students they needed to “pick” multiple adaptive attachment options (line 2) for their survival suits. He also reiterated to students that the entire class period would be dedicated to accomplishing this task (line 9), indicating he expected the task to not happen quickly. He also emphasized the paper handout seen in Figure 1, which he was displaying to the class. Mr. Mills noted that for students to justify their design decisions, they needed to provide explanations “backed up” (line 4) by the data provided. Additionally, he noted explanations backed up by other means (e.g., “it’s cool”) would not be accepted (line 5).

Extract 6 – *Instance #1*

Mr. M.	you will have today (..) a design sheet, with a suit outline and you must pick the adaptive attachment options for each part of the suit <we’ll talk about that in a second> okay (.) every CHOICE you make=today for how you design your suit must (.) be backed up (.) (holds the data sheet up) with data from the packet (.) do you understand this says a simple (.) yeah we should use this cause it’s cool (.) that’s not gonna be accepted I won’t take that=you understand↑ okay were using the entire class period to do this so that alone (.) should be enough to tell you that <a lot of detail is required> there’s nothing after this today

By discussing the task with his students in this manner, Mr. Mills demonstrated the importance for students to justify their design choices using the “expert authority” (van Leeuwen, 2007) provided via the data. He made clear other justifications such as “it’s cool” (line 5) would not be acceptable, thereby hoping to make the point that engineers use data to inform their decisions (Bucciarelli, 1994). His presentation of the task, however, and emphasis on using the data failed to provide students with space to use their own personal authority while engaged in the design problem space. This instructional decision, as described above (e.g., *theme 1*), played out differently for each of the student groups selected for this study (Lemke, 2012). In essence, students were discouraged from bringing their personal experiences and knowledge of the materials into the design task at hand because Mr. Mills clearly defined the structured parameters for students to engage in the task (Gee, 2010).

During the same day, with students now sitting at their tables discussing which options to pick for their survival suit, Mr. Mills began circulating around the room monitoring their progress and providing support as needed. After a few minutes, he stopped by Swani and Tina’s table as they were discussing which material type would help them survive in the cold, mountainous environment they were assigned.

Extract 7 – *Instance #6*

Mr. M.	° ° when making your decisions you wanna go based off of information that comes from this ° ° (referencing the data sheet)
Author 1	well they were looking at that too/
Mr. M.	NO I know I’m just saying but like you don’t wanna go just b/based on like OH I REMEMBER or I think it’s/what’s in that okay ↑ excellent
Swani	Okay

This particular class had not met for a few days and Mr. Mills seemed concerned students would be making design choices based on memory alone. He therefore entered into Swani and Tina’s conversation by reminding them they needed to make their decisions “based off of information that comes from this [the data tables]” (lines 1-2). The first author noted the pair was using the data because he had been working closely with them before Mr. Mills’ arrival (line 3). Mr. Mills acknowledged this (line 4), but again emphasized to students using negative examples of what not to say, by stating phrases (e.g., “I remember or I think”, lines 4-5) that would not be accepted. Much like in his introduction to the activity, when Mr. Mills entered into Tina and Swani’s conversation, he felt compelled to emphasize the importance of making design choice justifications using only an appropriate data source. Extracts 1 and 2 (*theme* 1) above displayed how in spite of the efforts Mr. Mills’ exhibited here, Swani and Tina still deemed it acceptable to use their personal authority when making their design decisions, which highlights how strongly the group was compelled to provide justifications for their design choices using their personal authority.

Mr. Mills continued to privilege the data as the means for students to support their design decisions throughout the remainder of the unit. In the next exchange, he had realized upon reflection that students struggled to use the data table from the temperature test because it did not include a column for the change in temperature (see Figure 1). This information was really what students needed to evaluate when deciding if certain materials would help keep them warm or cool inside their survival suit. On day 8, Mr. Mills wanted to work through this data table with his students before they continued discussing their designs.

Extract 8 – *Instance #14*

1	Mr. M	so tell me (.) according to the chart/ which one is the warmest↑
2	class	feathers (simultaneously)
3	Mr. M	okay. that’s the confusion we’re ch/clearing up today (.) okay=you know that if I made a
4		jacket out of fur it’s going to be warmer than a jacket out of feathers <you just know that,
5		right↑>
6	student	right
7	Mr. M	cause you see like my jacket when you <see me in the morning> is there fur around my
8	student	face
9	Mr. M	yeah:
10	student	yeah: right↑
11	Mr. M	are you warm in that
12		I am warm okay (.) now (..) the fact that it went up 12 degrees (.) the spot on the tray went
13	student	up 12 degrees and you had that hot lamp over it. What does that mean got through the
14	Mr. M	feather/
15		//the heat
16	student	//onto the/ the heat the heat went through the feather (.) onto the tray so: (pointing at
17	Mr. M	whiteboard) if it went up more does that mean more or less of the heat got through↓
18		more
19	student	more=more of the heat went through and made the tray hotter=does that make sense down
20	Mr. M	here did more or less of the heat get through
21	student	less
22	Mr. M	LESS because it did not get as hot do you understand
		yep
		so knowing that if we look at this chart↑ which material will keep you the warmest

Mr. Mills’ hunch that students had struggled to translate the information provided in the data table was quickly confirmed (lines 1-3). Students all believed the feathers were the best adaptive attachment option to keep them warm in a cold biome (line 2). Students appeared to select feathers because the temperature listed in the final column of the table for this option was the second highest, at 86.1 degrees, just slightly less than fish scales (Figure 1). Mr. Mills followed by giving students an example to consider involving a jacket, something students in the area wore in the winter (line 3). Next, he prompted students to use a familiar experience, wearing a jacket, and asked them to pick a material, fur or feathers, to make a jacket out of (lines 4-10). He also mentioned his own choice to wear a winter jacket that included a hood partially made out of fur (lines 7-8). He then walked students through a question/answer exchange, asking them to respond to either/or prompts, which the students gladly participated in (lines 13-24). Mr. Mills reduced the complexity of the problem students were facing in this exchange. They were not required to make sense of the data and use it as a means for justifying a design decision; instead they were made to believe Mr. Mills knew the right answer and that once they “got it right” they could move on designing their survival suit. Interestingly, Mr. Mills undoubtedly used his personal authority when describing how he knew fur would keep him warmer in the winter. In the end, though, he directed students’ attention to the data in the chart (line 22).

Discrepant Episode

Contrary to the extracts above, there were three instances when Mr. Mills did not focus on the data as the means for justification. On the final day of the unit, as mentioned before, students needed to redesign their survival suits to work in both their originally assigned environment as well as the prairie environment. At the end of this lesson students shared out the major changes they made to their survival suits as a result of this new design criterion. During this time, Swani volunteered to share a major change in color their group made.

Extract 9 – *Instance #31*

1	*Mr. M*	anybody else (.) Swani
2	*Swani*	um we changed these colors:↑ to pink and blue because we don't want to be seen
3	*Mr. M*	wait=wait=wait (.) you changed to pink and blue (.) because you <u>don't</u> want to // be
4		seen]
5	*student*	// ↓oh my god↓]
6	*Swani*	cause our color: is/
7		((students shift around a bit while still remaining seated))
8	*student*	you did pink and blue because those are your favorite colors
9	*Mr. M*	HOLD A SECOND HOLD ON HOLD ON (.) HOLD ON (..) what was your
10		environment=<what were your two environments> (.) you were: PRAIRIE (.) and:↑
11	*Swani*	mountain↓
12	*Mr. M*	MOUNTAIN (.) and you changed from orange and/
13	*Swani*	black
14	*Mr. M*	black <like a tiger> to pink (.) and blue=OK/ <u>WHERE</u>: do you see pink and blue
15		<u>naturally</u> on a mountain and in prairie↓
16	*student*	oh I know (..)
17	*Swani*	flowers
18	*Mr. M*	OH YEAH but are the flowers always there↑
19	*Swani*	// yeah]
20	*Mr. M*	// no:] no they are only there when it is↑
21	*Swani*	summer/
22	*Mr. M*	the rainy season remember (..) anybody else have any changes

Swani revealed her group changed their original color because they "didn't want to be seen" (line 3) in the new prairie environment. The class was startled by this announcement (lines 5, 7), which Mr. Mills quickly addressed (line 9). Mr. Mills wanted to give Swani a chance to clarify this design choice (lines 9-10) by first asking her to remind him and the class which environment their design suit was originally created to survive in (line 10). Mr. Mills then wanted to know where in each environment Swani noticed blue and pink (line 14). She responded by saying both habitats contained "flowers" (line 17). Mr. Mills followed by asking how often flowers were found there (line 18), which Swani admitted was only in the summer (line 21).

We categorized this exchange as discrepant because Mr. Mills did not ask Swani to provide a data source as means for justifying her choice to have a blue and pink survival suit. Instead of asking Swani to bring in the data students collected during the "camouflage test" he simply asked her to share why she thought this was the best choice. In the end, she was allowed to make the justification for picking pink and blue because she saw those colors in the prairie. In this example Swani was allowed to draw on her personal authority instead of being required to use the expert authority (van Leeuwen, 2007) the data had been given in the classroom.

This exchange was shown to Mr. Mills during the stimulated recall interview, and Mr. Mills picked up on the fact Swani was trying to use her personal experience for the justification. He noted that often students are initially "comfortable with using what (they) know … (which includes the use of) … their experience to justify their decisions." He went on to say this was "not exactly the way we want them to [justify their decisions]." When asked by the first author if there are "ways to allow for this sort of personal knowledge to come in along with the data?," Mr. Mills responded that he thought personal experiences and knowledge definitely played a role, but also noted students might bring misconceptions in their personal knowledge that could negatively affect their decision-making.

> Oh absolutely. I think personal experiences are a huge thing. Although I think, it's definitely going to be harder for children than for adults, but sometimes children will have personal experience that is not accurate. (*Stimulated-Recall Interview: Mr. Mills – May 2017).*

Mr. Mills definitely noted the importance of validating students' personal assets and resources in the classroom, but perhaps as others have noted found it difficult to know precisely what kinds of language students would be using (Lucero, 2012, Schleppegrell, 2004).

Theme 3 Summary

Mr. Mills' emphasized and privileged the use of data as a means for justifying design choices because that is one way professional engineers assess the value of a design they create (Bucciarelli, 1994). Of the groups observed in this study, only one group tried to enact the practice being promoted by Mr. Mills. However, while Group 2 did take up this practice, it is not entirely clear if they did so because they valued the use as data as a means to support their designs or if they were defaulting to Mr. Mills' role model authority (van Leeuwen, 2007, 2008). Group 2 did make statements such as "he [Mr. M.] wants to know how many how much it went up," thereby referencing his expectations and authority with their own utterances. Throughout all the instances categorized within theme 3, Mr. Mills clearly overemphasized that students needed to use the data to justify their design choices. Interestingly, though, only one student group choose to imitate this fully sanctioned method for participating in the discourse practices of engineering design, while the other did not (Lemke, 2012).

Discussion and Implications

With the presence of engineering education continuing to grow in elementary classrooms across the world, this study adds to an emerging body of research (Honey, Pearson, & Schweingruber, 2014; Kelley, Capobianco, & Kauf, 2015) by aiming to understand how teachers and students could begin to navigate and negotiate the discursive demands of engineering-specific discourse practices by focusing on the use of data within the design problem space (Moje et al., 2001; NRC, 2012). More specifically, the current study revealed how two groups of elementary students justified their engineering design choices by calling attention to the knowledge systems and authorities they drew on for making those justifications (Gee, 2010; Moje et al., 2001). When examining the different ways students justified their design choices, the results revealed Group 1 primarily drew on past, relevant experiences during the task, thereby enacting their own personal authority (van Leeuwen, 2007, 2008). Tina and Swani comfortably provided justifications for their adaptive attachment options without feeling they needed to bring up specific pieces of data, despite Mr. Mills' repeated emphasis that students make data-informed decisions. In the end, their cumulative efforts (Walton & Krabbe, 1995) helped them come up with a list of adaptive attachment options they felt reached the design criteria they needed to meet for the design challenge. We would also like to acknowledge the optics of seemingly presenting a group of female students in a stereotypical manner (i.e., only enacting personal authority while disregarding "hard" data). The first author, as a participant observer, acknowledged that during the unit other female groups did enact varying authorities while discussing their survival suits, some of which utilized relevant data sources.

Next, and because this study relied on semi-guided (i.e., design sheet), uncontrollable student discourse, it is difficult to know if Swani and Tina's *thinking* may have been influenced by the data even though it never explicitly came out in their conversation. It is possible the materials tests they conducted previously did inform their thinking, but because the study did not include reflective prompts asking about this throughout the design process (e.g., Wendell, Wright, & Paugh, 2017) those data were not collected. While a limitation of the current study, we believe this opens up opportunities for future research. More specifically, we feel this finding highlights the importance of supporting students in not only understanding how to interpret and analyze data (NRC, 2012), but also in how to build connections with the personal authority they bring to a design activity (Brown, 2017; Lemke, 1990). Additionally, we need novice learners to understand how purposefully collected data can be used in support of their personal understandings, knowledge bases, and experiences (Cunningham & Kelly, 2017). More specifically, students need to understand that when engineers conduct a rigorous process of testing and analysis (Vincenti, 1990) it then enables them to reassert the value of their design ideas (Bucciarelli, 1994), which may have originated via a relevant, personal experience just as Swani did when referencing her experience to a mountainous biome. If students are going to learn anything substantive during the engineering design process, aside from various procedures, they must feel empowered to draw on and actualize their own distinct forms of "sociohistorical knowledge" (Cunningham & Kelly, 2017) just as professional engineers do (Cross, 2003) during the engineering design process.

Contrary to Group 1, Group 2 primarily relied on the data they collected during the materials tests to justify their design choices. Within this group, students discussed, argued about, and eventually reconciled their ideas concerning each adaptive attachment option while moving towards a desired endpoint (Walton & Krabbe, 1995). Furthermore, Group 2 readily identified and focused in on specific forms of data as a means for discussing which choice made the most sense, often while thinking about relevant disciplinary ideas (e.g., *extract 6*). While Group 2 did engage in spirited conversations surrounding the data they were analyzing as engineers do (Bucciarelli, 1994), they also acknowledged (and stated) this practice was simply something Mr. Mills wanted them to do (Barton & Yang, 2000). Again, it is therefore unclear if they actually understood how the data they collected provided them with the best justifications for choosing a specific adaptive attachment option, or if they just understood how to "play the game" of school and were merely submitting to Mr. Mills' authority and attempts of control within the classroom (Reinsvold & Cochran, 2011). As depicted in *theme 3*, Mr. Mills continually reminded his students to use applicable data to support their design decisions. He even went so far as to tell his students they could not just use what they knew, understood, or remembered from the testing when justifying their choices (e.g., *extract* 7). Instead, they needed specific numbers backing up each claim. This is not to say we feel Mr. Mills did anything wrong within his classroom by emphasizing the data. Rather, the professional development context he participated in emphasized student learning about, and engagement with data measurement and analysis. Additionally, this was the first time Mr. Mills implemented this newly-created unit. It was therefore unknown to him and ourselves what types of language students would need and be using once implemented (Lucero, 2012, Schleppegrell, 2004). In hindsight, the unit he was implementing likely emphasized these practices (i.e., data measurement and analysis), likely beyond what was needed.

Tensions within the Design Problem Space

Within the design problem space elementary students will bring numerous personal experiences, beliefs, and knowledge to the content and activities being explored (e.g., Lemke, 1990). Within this space and given the likely use of common, everyday materials, it is likely students will naturally possess some forms of knowledge that will support their understanding of how to develop an effective design solution while engaging in these experiences (Metz, 2008). Furthermore, they may not initially feel their design choices always require specific data to be justified. As others have highlighted (Kittleson & Southerland, 2004), a "discursive competition" and ensuing tension emerges between the goals of the teacher and the practices students are willing to and want to engage in. This finding highlights an interesting tension for engineering education at the elementary level worthy of continued investigation. While it is desirable that students understand the work engineers do (e.g., Bucciarelli, 1994), it is unlikely they will understand the knowledge-generation process inherent within discourses if they feel their own personal ways of knowing do not have a place within this particular domain (Kelly, 2008). Within the classroom, the *instructional congruence model* (Lee & Fradd, 1998; Lee & Luykx, 2005) provides a potential bridge capable of building connections between students' science (and likely engineering) learning to their cultural discourses and knowledge. Future research should look to preexisting frameworks (Lee & Luykx, 2005) to examine further how these tensions can be resolved within classrooms that emphasize engineering discourses during engineering design.

Finally, and as a means to counteract the likelihood students might cater their thinking and design choices to coincide with the presumed values of their teachers, future studies should continue to explore the infusion of publically accountable talk and whole-class reasoning (Mercer, Wegerif, & Dawes, 1999) when students begin exploring and considering a variety of design decisions. Beginning conversations should include students' initial design ideas, which again will likely be based on personal experience (Lemke, 1990). Moving forward, students' ideas should then be weighed against the constraints of the design challenge all the while knowing they will eventually collect data and modify their original design ideas in an iterative fashion (Crismond & Adams, 2012; NRC, 2012). As students continually move through the design process and while periodically coming together collectively as a group, they should then begin to see how their diverse design ideas, once tested, can then be furthered via discourse that engages them in the practices of judging, assessing, and evaluating (Engle & Conant, 2002), thereby turning their legitimations more towards one that is data driven, while still providing space for them to enact their personal discourses. The aim is not for students to just blindly follow a specific procedure or practice, but rather to truly engage them in an intriguing and difficult problem space that necessitates their active engagement. Similar to past reforms in science education wherein the content was overemphasized via rote memorization (e.g., Metz, 2008), we again do not want students to feel engineering needs them to cater to the desires and needs of the classroom teacher. These findings highlight the important role that teachers play in supporting their students in making these connections, to further students' understandings and their use of data in support of their engineering design solutions. We believe that this work adds to the emerging, but limited research on engineering practices in elementary classrooms, and opens possibilities for future research to explore when and how students choose to use data to support their design decisions, and how teachers can support and leverage personal knowledge and understandings in concert with data collected in the classroom.

Notes

This work was supported by the National Science Foundation under grants #1238140. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Allen, M. (2006). *Misconceptions in primary science.* McGraw-Hill Education (UK).

Anderson, R.D. (2007). Inquiry as an organizing them for science curricula. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 808-830). New York: Routledge.

Bakhtin, M. (1986). The problem of speech genres (V. McGee, Trans.). In C. Emerson & M. Holquist (Eds.), *Speech genres and other late essays* (pp. 60–102). Austin: University of Texas Press. (Original work published 1953).

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.

Bigelow, M., Ranney, S., & Dahlman, A. (2006). Keeping the language focus in content-based ESL instruction through proactive curriculum-planning. *TESL Canada Journal/Revue TESL Du Canada*, *24*(1), 40–58.

Brown, B. A., Reveles, J. M., & Kelly, G. J. (2005). Scientific literacy and discursive identity: A theoretical framework for understanding science learning. *Science Education, 89,* 779–802.

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *Journal of Research in Science Teaching*, 54(9), 1143–1173.

Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Bucciarelli, L. (1994). *Designing engineers*. Cambridge, MA: MIT Press.

Carr, R. L., Bennett, L. D., IV, & Strobel, J. (2012). Engineering in the K-12 STEM standards of the 50 U.S. States: An analysis of presence and extent. *Journal of Engineering Education, 101*(3), 539-564.

Calderhead, J. (1981). Stimulated recall: A method for research on teaching. *British journal of educational psychology*, *51*(2), 211-217.

Capobianco, B. M., Yu, J. H., & French, B. F. (2014). Effects of engineering design-based science on elementary school science students' engineering identity development across gender and grade. *Research in Science Education*, *45*(2), 275-292.

Cazden C. B. (2001). *Classroom discourse: The language of teaching and learning* (2nd edition). Portsmouth, NH: Heinemann.

Cunningham, C. M., & Carlsen, W. S. (2014). Precollege engineering education. In N. G. Lederman, & S. K. Abell (Eds.), Handbook of research on science education. New York: Lawrence Erlbaum Associates.

Cunningham, C., & Hester, K. (2007). *Engineering is elementary: An engineering and technology curriculum for children.* Paper presented at the American Society of Engineering Education Annual Conference and Exposition, Honolulu, HI.

Cunningham, C. M., & Kelly, G. J. (2017a). Epistemic practices of engineering for education. *Science Education, 101*, 486–505. Doi.org/10.1002/sce.21271.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), 738–797.

Cross, N. (2003). The expertise of exceptional designers. In N. Cross & E. Edmonds (Eds.), *Expertise in design* (pp. 23–35). Sydney, Australia: University of Technology Creativity and Cognition Press.

Duschl, R. A. (2000). Making the nature of science explicit. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 187–206). Buckingham, UK: Open University Press.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*(4), 399 – 483.

Erickson, F. (1992). Ethnographic microanalysis of interaction. *The handbook of qualitative research in education*, 201-225.

Gee, J. P. (2001). *An introduction to discourse analysis: Theory and method*. Routledge: New York.

Gee, J. (2008). Essay: What is academic language? In A. S. Rosebery & B. Warren (Eds.), *Teaching science to English language learners: Building on students' strengths* (pp. 57–70). Arlington, VA: NSTA Press.
Gee, J. P. (2010). *How to do discourse analysis: A toolkit.* Routledge: New York.
Hanushek, E. A., Woessmann, L., Jamison, E. A., & Jamison, D. T. (2010). Education and economic growth. *International Encyclopedia of Education*, *(2)*, 245-252.
Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press: Washington, DC.
Henderson, K. (1991). Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. *Science, Technology, and Human Values*, *16*(4), 448–473.
Fortune, T., Tedick, D., & Walker, C. (2008). Integrated language and content teaching: Insights from the immersion classroom. In T. Fortune & D. Tedick (Eds.), *Pathways to multilingualism: Evolving perspectives on immersion education* (pp. 71–96). Clevedon: Multilingual Matters.
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The Journal of the Learning Sciences, 4(1), 39–103.
Kelly, G. J. (2008). Learning science: Discursive practices. In Encyclopedia of language and education (pp. 1071-1082). Springer US.
Kelly, G. J. (2014). Discourse practices in science learning and teaching. In N. G. Lederman, & S. K. Abell (Eds.), Handbook of research on science education (2) (pp. 321–336). Mahwah, NJ: Lawrence Erlbaum Associates.
Kelley, T. R., Capobianco, B. M., & Kaluf, K. J. (2015). Concurrent think-aloud protocols to assess elementary design students. *International Journal of Technology and Design Education*, *25*(4), 521-540.
Keefer, M. W., Zeitz, C. M., & Resnick, L. B. (2000). Judging the quality of peer-led student dialogues. Cognition and instruction, 18(1), 53-81.
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.
Kittleson, J. M., & Southerland, S. A. (2004). The role of discourse in group knowledge construction: A case study of engineering students. *Journal of Research in Science Teaching*, *41*(3), 267-293.
Lachapelle, C. P., & Cunningham, C. M. (2014). Engineering in elementary schools. Engineering in pre-college settings: Synthesizing research, policy, and practices. Lafayette, IN: Purdue Univ.
Lee, O. & Fradd, S.H. (1998). Science for all, including students from non-English language backgrounds. Educational Researcher, 27, 1–10.
Lee, O., & Luykx, A. (2005). Dilemmas in Scaling up Innovations in Elementary Science Instruction with Nonmainstream Students. *American Educational Research Journal*, *42*(3), 411–438.
Lemke, J. L. (1990) Talking science: Language, learning and values. Norwood, NJ: Ablex Publishing Corporation.
Lemke, J. L. (2012). Analyzing verbal data: Principles, methods, and problems. In *Second international handbook of science education* (pp. 1471-1484). Springer Netherlands.
Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. School Science and Mathematics, 116(4), 177-188.
Lucero, A. (2012). Demands and opportunities: Analyzing academic language in a first grade dual language program. *Linguistics and Education*, *23*(3), 277–288.
Metz, K. (2008). Narrowing the gulf between the practices of science and the elementary school classroom. Elementary School Journal, 109, 138–161.
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), 2.
Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of engineering in K-12 state science standards. *Journal of Research in Science Teaching*, *52*(3), 296-318.
National Research Council. (2009). Engineering in K–12 education: Understanding the status and improving the prospects. Washington, DC: National Academies Press.
National Research Council. (2012) A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.
Next Generation Science Standards Lead States. (2013). Next generation science standards: For states, by states. Washington: The National Academies Press.
National Academy of Engineering and National Research Council. (2007). Rising above the gathering storm: Energizing and employing America for a brighter economic future. Washington, DC: The National Academies Press.
National Academy of Engineering & National Research Council (2009). Engineering in K-12 education: Understanding the status and improving the prospects. (Eds. Katehi, L. & Feder, M.). Washington DC: National Academies Press.

National Research Council (US). Committee on Highly Successful Schools or Programs for K-12 STEM Education. (2011). Successful K-12 STEM education: Identifying effective approaches in STEM. National Academies Press.

National Academy of Engineering and National Research Council. (2014) STEM integration in K-12 education: Status, prospects, and an agenda for research. Washington, DC: The National Academies Press.

National Academy of Engineering [NAE] & National Research Council [NRC]. (2014) STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research. Washington, DC: The National Academies Press.

National Research Council. (2009) Engineering in K-12 Education: Understanding the Status and Improving the Prospects. Washington, DC: The National Academies Press.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.

National Academy of Engineering and National Research Council. (2009). *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*. L. Katehi, G. Pearson, and M. Feder, Editors. Washington, DC: The National Academies Press. Available at https://www.nap.edu/catalog/12635, accessed March 10, 2017.

National Academy of Engineering and National Research Council. (2014). *STEM Integration in K–12 Education: Status, Prospects, and an Agenda for Research*. M. Honey, G. Pearson, and H. Schweingruber, Editors. Washington, DC: The National Academies Press.

National Science Foundation. (2010). Preparing the next generation of STEM innovators: Identifying and developing our nation's human capital. Washington, DC: Author.

Mangiante, E., & Moore, A. (2015). Implementing inclusive engineering challenges for elementary students. Kappa Delta Pi Record, 51(3), 131-137.

Majors, Y. (2007). Narrations of cross cultural encounters as interpretative frames for reading word and world. Discourse & Society, 18, 479–506.

Marco-Bujosa, L. M., & Levy, A. J. (2016). Caught in the Balance: An organizational analysis of science teaching in schools with elementary science specialists. *Science Education*, *100*(6), 983-1008.

Martin, A. M., & Hand, B. (2009). Factors affecting the implementation of argument in the elementary science classroom. A longitudinal case study. *Research in Science Education*, *39*(1), 17-38.

McNeill, K. L., & Berland, L. (2017). What is (or should be) scientific evidence use in k-12 classrooms?. *Journal of Research in Science Teaching*, *54*(5), 672-689.

Mercer, N. (1995) *The guided construction of knowledge: talk amongst teachers and learners* (Cleve-don, Multilingual Matters).

Mercer, N., Wegerif, R. & Dawes, L. (1999) Children's talk and the development of reasoning in the classroom, *British Educational Research Journal*, 25(1), 95–111.

Moje, E. B., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is 'quality'?": Language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching*, 38(4), 469-498.

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), 2.

Novak, J. D. (1977). A theory of education. Ithaca, NY: Cornell University Press.

Ochs, E. (1979). Transcription as theory. *Developmental pragmatics*, *10*(1), 43-72.

Patton, M. (2002), Qualitative evaluation and research methods. Beverly Hills, CA: Sage.

Reinsvold, L. A., & Cochran, K. F. (2011). Power dynamics and questioning in elementary science classrooms. Journal of Science Teacher Education, 23(7), 745-768.

Roschelle, J., Bakia, M., Toyama, Y., & Patton, C. (2011). Eight issues for learning scientists about education and the economy. The Journal of the Learning Sciences, 20(1), 3-49.

Samuel, A. E. (1986). Student centered teaching in engineering design. Instructional Science, 15(1), 213-238.

Schleppegrell, M. J. (2004). *The Language of Schooling: A Functional Linguistics Perspective*. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Van Leeuwen, T. (2007). Legitimation in discourse and communication. *Discourse & Communication*, *1*(1), 91-112.

Van Leeuwen, T. (2008). *Discourse and practice: New tools for critical discourse analysis*. Oxford: Oxford University Press.

Vincenti, W. G. (1990). What engineers know and how they know it. Baltimore, MD: Johns Hopkins University Press.

Vygotsky, L. V. (1978). The mind in society. Cambridge, MA: Harvard University Press.

Wolcott, H. F. (1994). *Transforming qualitative data: Description, analysis, and interpretation*. Sage.

Yu, J. H., Luo, Y., Sun, Y., & Strobel, J. (2012). A conceptual K-6 teacher competency model for teaching engineering. *Procedia - Social and Behavioral Sciences*, *56*, 243-252.Zhai, J., & Tan, A. L. (2015).

Roles of teachers in orchestrating learning in elementary science classrooms. *Research in science education*, *45*(6), 907-926.

Author Information

Karl G. Jung
University of South Florida
4202 E. Fowler Ave., EDU 105
Tampa, FL 33619
Contact e-mail: *karljung@usf.edu*

Justin McFadden
University of Louisville
1905 South 1st Street
Louisville, KY 40292

Appendix. Supplemental Material

Transcriptions conventions – Adapted from Majors (2007) and Oochs (1979)

Definition	Code
Descriptive text	(( ))
Laughter	@,@
Overlapping speech	[ ]
Increased volume	UPPERCASE
Indicates emphasis	Underline
Decreased volume	° °
Animated tone	!
Latched or continuous speech	=
Inaudible speech	( )
Stretching of sound	:
Short pause	(.)
Longer pause, indicates length of pause	(3.0)
Dropped or interrupted utterance	/
Falling intonation	↓
Rising intonation	↑
Faster relative speech	< >