# Emergence of an engineering identity in elementary students

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Abstract

This study examines the emergence of engineering identity among elementary school students. Engineering has only recently been added to state and national standards. One engineering unit from each of two teachers was analyzed from an extensive video record of over 96 engineering units over the course of four years. The purpose of the study was to examine ways that engaging in engineering practices transforms students' views of engineering and themselves. Across these two, four-lesson engineering units (designing parachutes and designing a mortar mixture for a stone wall) a sociolinguistic perspective is taken to show how engagement in engineering builds student identity. Because engineering is a new discipline in most classrooms, it provides a unique opportunity to examine how disciplinary affinity can be developed through purposeful activity and metadiscourse about participation.

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The *Next Generation Science Standards* (NGSS Lead States, 2013) propose to integrate engineering education into science education. Engineering offers new ways to learn science and fosters a unique set of epistemic practices specific to engineering design (Cunningham & Carlsen, 2014). These standards advocate for three-dimensional learning, comprised of science and engineering practices, crosscutting ideas, and disciplinary core concepts. Although engineering has recently entered into elementary education as a part of science curricula, efforts to include engineering existed prior to the onset of this round of reform (Cunningham, Knight, Carlsen, & Kelly, 2007; Schauble et al., 1991). Despite this history there has been little research into the teaching and learning of engineering through observation in K-12 classrooms, and even less on student take up of engineering practices and identity (Kelly, 2014a). Affiliation and identity development are related to student learning and are important issues for building students' understanding of disciplinary knowledge. The study takes a sociocultural perspective that recognizes the ways that knowledge and practices are constructed in and through discourse processes.

This study examines the enacted curriculum of two classrooms—a 4th grade aerospace engineering unit and a 5th grade geotechnical engineering unit. We consider the ways that the teacher and students construct meaning about the nature of engineering design and focus on ways the teachers use engineering curricula to frame and define engineering practices with these students. In particular, we focus on how by engaging in meaningful, real-world engineering challenges, children come to view the work they are doing as "engineering" and themselves as "engineers." Central to developing such identities are a set of discourse practices. Engineering provides a unique opportunity to examine how disciplinary affinity can be developed through purposeful activity and meta-discourse about participation.

## Cultural studies of education and engineering

### *Language and learning in science and engineering*

Research in science education has identified ways that language mediates interaction and knowledge acquisition (Kelly, 2014a; Lee & Fradd, 1998; Lemke, 1990). Much of the work of inquiry-oriented classrooms, like the ones studied here regarding engineering design, concern students learning to engage in sets of disciplinary epistemic practices. Epistemic practices are socially organized and interactionally accomplished ways that members of a group propose, construct, communicate, assess, and legitimize knowledge claims (Kelly, 2008; 2011). In science and engineering fields, such practices entail social languages or discourses with particular features, often emerging out of the needs of professional work (Bazerman, 1988) and with unique linguistic features (Halliday & Martin, 1993). These discourses come with ways of being in the world (Gee, 2001) and are potentially alienating for students, as their everyday way of speaking and interacting is often not valued in educational settings (Brown, 2006). In this study, the ways of talking and writing about engineering design projects and analysis provided the basis for investigating ways of building affiliation with engineering.

This research orientation is based on a set of substantive assumptions regarding cultural practices (Castanheira, Crawford, Dixon, & Green, 2003; Kelly 2014b; Kelly & Green, 1998). From the sociocultural perspective taken in this study, as members of a group affiliate over time, they create through social interaction particular ways of talking, thinking, acting, and interacting. These ways of being come to define a language of the classroom and set norms and expectations for actions taken among members. Over time these ways of acting become routinized, and patterns develop that define the cultural practices of the group. Such practices become resources for members as they are internalized and become part of the ways of being in the classroom. Cultural practices become the everyday ways of being for members of the group, but are also transformed as members modify these practices to establish and position new identities and ways of being. The cultural practices that constitute membership in a community are created interactionally through discourse processes. Thus, student identity, while constructed over time and drawing from multiple social languages, is dependent on the discourse practices of the local group (Brown et al., 2005). Such local group members are also members of other groups, and thus bring frames of reference to each interaction, including experiences, beliefs, values, knowledge and practices (e.g., ways of knowing, doing, interpreting), that may match or clash with local ones (Kelly & Green, 1998). From this perspective, identity is built through social interaction and importantly, particular discourse processes (Anderson, 2009; Carlone, Scott, & Lowder, 2014).

*Discourse and identity in education*

In our framework, individuals and groups construct identities as they talk, act, and affiliate as a group over time (Gee, 2001; Kelly & Green, 1998). Individuals in a social group act and interact as they develop their roles and situate themselves in the collective, thus defining for themselves and their fellow members their current and future positions. Identity formation considers how members of the group choose to participate as well as how they are positioned by others; to understand the construction of identity therefore, analyses must examine actions in moment-to-moment discursive events and then situate these in the larger context of interactional sequences (Kelly, 2008). In everyday life as well as school, people learn through participation in social groups. They become familiarized with norms of the group, building repertoires of discourse and interactions that may be understood, accepted, or rejected by the group. From a sociocultural point of view, identity is intricately connected to social relations between and among members of a group. It considers how someone views him/herself, how s/he is positioned by others in the group, how identities are taken up and morph over time, how individuals establish agency, and how individuals as members of a group construct repertoires for participation. We consider how studies of identity have been treated in science and engineering education. These fields have some commonalities (related to STEM reform, and both are listed as disciplinary core ideas in the NGSS (NGSS Lead States, 2013))—including problems building interest and affinity over time (Sjøberg & Schreiner, 2010).

Research on identity in science education (Anderson, 2009; Archer, DeWitt, Osborne, Dillon, Willis, & Wong, 2010; Carlone, Scott, & Lowder, 2014) has identified the ways that children perceive a 'mismatch' between their (desired) identity (e.g., as feminine, socially capable) and their perception of a "scientific identity" (e.g., masculine, "egghead"). Brown (2006) characterized this mismatch as how students pay a cultural cost, through the participation in discursive practices of science. This cost is particularly acute for marginalized students who need to be become bicultural to engage in both their cultural and science practices. Reveles, Cordova, and Kelly (2004) focused on the importance of engaging students in authentic scientific practices *as well as* in meta-discourse about those practices, in order for students to begin to associate their own actions with those of scientists (developing a science identity). Through a process of engaging in practices, and learning the language of science, the students came to perceive themselves as more capable learners (academic identity). Varelas, Kane, & Wylie (2012) also examined ways that classroom interaction develops identity among students. By focusing on student representation of knowledge in science journals, they identified how thirty black elementary students (grades K-2) came to see themselves as scientists and with science. The creation of the journals and conversations around the journal entries helped develop confident and hopeful science identities for the students.

As the field on pre-college engineering education is relatively new and research trends are still emerging, there are fewer studies of students' identities related to engineering (Cunningham & Carlsen, 2014). Silver & Rushton (2008) assessed year-5 students (UK, approximately age 9) prior to participation in a Science, Engineering & Technology (SET) classroom intervention. The study used Likert-scale questionnaires and children's drawings of scientists and engineers at work to investigate their attitudes toward Science, Engineering & Technology and their images of scientists and engineers. Regarding engineering they found students expressed both positive and negative attitudes toward engineering and viewed the fields as primarily concerning with "repairing" devices. Capobianco and her colleagues have completed a number of studies in the area of engineering identity. Capobianco, Diefes-Dux, Mena, & Weller (2011) completed a descriptive study of children in grades 1-5 (ages 6-11) about students' conceptions of an engineer, through the use of the Draw an Engineer Test (DAET) (Knight & Cunningham, 2004). Capobianco et al. founds that children saw engineers as mechanics, laborers, and/or technicians (fixing, building, or making and using vehicles, engines, and tools), and mostly male. These findings were mostly consistent across settings, gender and grade level, except that urban students viewed engineers more as laborers, whereas suburban students viewed engineers mostly as technicians, suggesting that images are socially influenced. Capobianco, French, & Diefes-Dux, (2012) applied the Engineering Identity Development Scale (EIDS)—a Likert-scale instrument for elementary students. Two important factors emerged from this study for the description of student identity. One component was the students' academic identity (i.e., self-beliefs or self-images as students) and the second was the notion of a possible engineering career (i.e., what engineers do, who students want to become). The authors found that students' identity was not fixed, but rather related to their "own lived learning experiences with engineering-related tasks" (p. 709). Capobianco, Yu, & French (2014) also used the EIDS instrument and interviews of students in a quasi-experimental pre/post intervention study of elementary students engaged in engineering design-based science activities. They found that students who engaged in the engineering intervention had greater gains on the EIDS than the comparison group. In particular, they had significantly greater understanding of engineering as a profession. These gains varied across grade levels with students in the lower grades showing substantial increases in their understanding of engineering as a profession and their interests in engineering as a career, whereas upper grade students maintained or decreased their understandings and career interests. The younger students also expressed more positive attitudes toward becoming an engineer than older students. In addition, on the academic subscale, girls in every grade showed greater gains than the boys for measures of confidence in their work as students, problem solvers, and members of their schools.

While some studies of science education and identity have brought a sociocultural perspective to the research, reflected in research methods focused on discourse and social practice, studies of identity in engineering have not yet taken this point of view. Our study seeks to ameliorate this by complementing the current cognitive studies of engineering identity by focusing on student identity as interactionally accomplished through discourse and action in classroom settings. To do this, we first turn to the study of engineering practices in professional settings.

*Empirical studies of engineering practices*

Learning engineering, science, and other academic disciplines entails understanding the nature of the knowledge and the ways that communities produce claims (Kelly, 2008; Ricketts, 2014). In engineering, such claims are often tied to specified features of a local condition. In other academic areas, knowledge may be tied to the interpretation of primary sources (history) or the results are experimentation (science). Such variation suggests a need to consider the epistemic practices of relevant disciplinary communities. Kelly and Licona (2015) define epistemic practices as the socially organized and interactionally accomplished ways that members of a group propose, communicate, justify, assess, and legitimize knowledge claims. Epistemic practices have four characteristics (Kelly, 2015). First, epistemic practices are interactional—they are constructed among people through concerted activity. Through discourse processes, members of a group frame opportunities to define what counts as knowledge and knowledge claims. Second, epistemic practices are contextual. These interactionally constructed practices occur in social settings, in time and space, and are framed by cultural norms. Third, epistemic practices are intertextual. Proposing, justifying, assessing and legitimizing knowledge claims rely on and make use of discourse, signs, and symbols make reference to other discourses. These signs, symbols, and texts are communicated from a history of socially recognized genres of communication. Fourth, epistemic practices are consequential. Choices about what counts as reliable, valid, or useful legitimize certain knowledge claims that instantiate power and culture.

Cunningham and Kelly (in review) reviewed an extensive body of the practice of professional engineering (e.g., Anderson, Courter, McGlamery, Nathans-Kelly, &

Niometo, 2010; Madhavan, 2015; Vincenti, 1990). Through these studies of engineering *in situ*, and initial studies of engineering in educational settings (Cunningham & Kelly, in review), a number of key practices for education were identified. This analysis identified a set of 16 epistemic practices of engineering. These practices can be categorized into four areas: social contexts of engineering, uses of data and evidence to make design decisions, tools and strategies to solve problems, and ways of employing creativity and innovation in design and analysis. Table 2 provides a list of these practices in column one. These epistemic practices of engineering served as a basis for the initial interpretation of the students and teachers' work in the engineering curricular units in this study.

**Educational Setting**

*Curriculum units*

Two teachers were selected from a corpus of data from video record of over 96 engineering units over the course of four years. The teachers and corresponding units were chosen as positive test cases for how to engage students in engineering practices. As there are many examples of children losing interest in STEM education (Archer, DeWitt, Osborne, Dillon, Willis & Wong, 2010; Tai, Liu, Maltese, & Fan, 2006; Vedder-Weiss & Fortus, 2011, 2012), and a high attrition rate at the college level (Chen, 2009, 2013; Hayes, Whalen & Cannon, 2009; Ohland, Sheppard, Lichtenstein, Eris, Chachra, & Layton, 2008; Ngambecki, Evangelou, Long, Ohland, & Ricco, 2010), we focused on how affiliation and success can be constructed in schools with diverse populations. The instructional units are two units in the Engineering is Elementary® (EiE) curriculum. Engineering is Elementary is an elementary engineering curriculum developed by the Museum of Science, Boston that seeks to foster engineering literacy in students in grades 1-5.

EiE integrates engineering concepts with science topics that children study in elementary school. The EiE team identified the 20 most commonly taught science topics in elementary school and, for each, designed a curriculum unit that asks students to use the science concepts they have learned to solve an engineering design challenge focused on a particular field of engineering such as biomedical, green, or electrical engineering. Each unit begins with an illustrated storybook in which a child from a country around the world confronts a problem that s/he solves using the engineering design process. The 20 EiE units follow a standard format, consisting of four lessons preceded by a preparatory lesson. The two instructional units for this study were the aerospace engineering unit, *A Long Way Down: Designing Parachutes* (EiE, 2011a), designed to connect to children's study of astronomy, and the materials engineering unit, *A Sticky Situation: Designing Walls* (EiE, 2011b) designed to integrate with science units that focus on earth materials. . A short description of the units is presented in Table 1.

Both of these curricular units organize the students' activities around the Engineering Design Process (EDP). As engineers work to design solutions that solve problems they generally approach them in systematic and data-driven ways. The process they use, the engineering design process, can be simplified into a series of iterative phases or steps. At the collegiate or professional level the process can have over a dozen steps. The age-appropriate engineering design process that serves as the backbone of the EiE units has five steps: Ask, Imagine, Plan, Create, and Improve. As students engineer their technologies, these steps help focus them on the goal for their activities.

*Teacher and school background*

The parachutes engineering unit was taught by Jean, a Caucasian women, had been a classroom teacher for eleven years when we collected the video data from her class. Prior to this, she partnered for six years as a pilot teacher for the EiE curriculum. In this role, she attended curriculum development meetings 3-4 times a year, piloted EiE units, provided detailed feedback about EiE activities and lessons and how they could be improved, and permitted EiE staff to observe her teaching, interview her students, and collect formative evaluation surveys from her pupils. Jean piloted eleven EiE units with her students, providing feedback to the development team about how they could be improved. By the onset of this study, Jean was a highly skilled engineering teacher; she had a deep knowledge of engineering practices and could lead instruction that engaged children in these, she was comfortable including engineering in her curriculum and was sought out as a mentor by other teachers, and she had offered professional development for other teachers about elementary engineering.

During the 2011–2012 school year, Jean was asked to teach the fourth-grade Gifted and Talented Education class. This was a full-day class for 24 students—14 girls and 10 boys. Jean taught in an urban district in a southeast city in Massachusetts. The elementary school had about 800 students; approximately 70% of the students were low income, 24% were children with disabilities, and 5% were English Language Learners. Approximately 65% of the school is white, 6% Black, 3% Asian, 18% Latino, and 8% multiracial. While we could not secure demographics for individual students in Jean’s class, they seemed to mirror the larger school population. Jean’s class engaged in two EiE engineering units during the school year; this study focuses on the second EiE unit.

Chentel, an African-American woman, taught the walls engineering unit to her class of second graders. Chantal had been a classroom teacher for 6 years when she permitted us to film her engineering instruction. The unit we filmed was the first time Chentel had taught EiE or engineering to her pupils. She had attended a one-day professional development workshop, which introduced her to engineering and the EiE curriculum.

Chentel taught in a Title I magnet school in southeast Florida. The school had a focus on STEM. The school’s student population was 94% minority, 92% of students were eligible for free and reduced lunch. The Florida State assigned school grades was a “D”. During the 2013-14 school year Chentel taught the second grade gifted/high achiever classes for the first time. These classes are required in her county for grades 3-5 and a school-based decision for grades K-2. Chentel had 18 students in her class—half girls, half boys. The demographics of the students in the class seemed to mirror those of the larger school.

## Research Methods and Approach

*Ethnographic questions*

The analysis focuses on ways that teachers and students engaged across a set of interactions while working in an elementary engineering curriculum *Engineering is Elementary*, 2011a&b). Previous research identified how investigations and engineering design processes provide opportunities to define the nature of engineering knowledge and practice in these contexts (Cunningham & Kelly, 2015). This unique setting provides an opportunity to examine how engagement with and talk about engineering offers ways for students to develop academic engineering identities and build affiliation with engineering as a field of inquiry. We posed the following research questions:

- How does student take-up of engineering practices build knowledge of and affiliation with engineering?
- In what ways is the development of a student an engineering identity supported by the discourse practices of the teachers?

To address these questions, we took an ethnographic approach, informed by sociolinguistic discourse analysis (Castanheira, et al., 2003; Gumperz, 2001). Our research methods included analysis of videodata and associated classroom artifacts. We sought to understand the ways that elementary engineering was interactionally accomplished among the teachers and students, and how through these processes, students were able to engage in the epistemic practices of engineering and learn to assume an engineering identity. This approach begins with an initial period of ethnographic research that seeks to understand insights into local communicative ecologies, discover recurrent communicative patterns, and identify how local actors define problems (Gumperz, 2001). This orientation allowed us to identify how students' actions, and the teachers' positioning of students with discourse, builds identity in engineering education.

*Data sources and representations*

To address these questions, we collected videotape data with two cameras of the entire units (approximately 8 - 12 hours each in duration across four lessons) in the two classrooms engaged in engineering units. Our analysis focused on the ways that disciplinary practices of engineering were framed, taken up, enacted, and named by the teachers and students over time. We created transcripts of the talk and action and analyzed associated classroom artifacts. We drew from sociolinguistics and educational ethnography to consider ways that classroom talk framed the disciplinary practices and how through engagement and talk about engineering practices the potential for student identity as engineers is developed (Kelly, 2014a&b).

This process began by transcribing the classroom discourse and using contextualization cues to build and frame ways that the participants constructed the instructional conversations (Castanheira, et al., 2003; Crawford, 2005). Through this process, we created event maps, showing the ways that the classrooms spend time and effort on various activities. These event maps provide a time-stamped record allowing for sequential analysis of the various events (Kelly, 2014a; Wortham, 2003, 2008). Example of an event map is presented in Figure 1. In this sample, the event map shows the one phase unit (presentation of student “Imagine” spacecrafts) and a series of time-stamped sequence units. The lines of talk are separated turn units—sometimes turns of talk were separated due to shifts in thematic content. The time-stamped event maps included all of the transcribed talk across the four lessons for each classroom. These maps were completed in Microsoft Excel, allowing for extended columns of codes synced to the talk and action.

For each lesson, spanning a number of instructional days, we identified events (bounded activity around a particular topic and purpose), phase units (concerted and coordinated action of participants reflecting a common content focus), and sequence units (cohesive thematically-tied interactions) following approach of Kelly, Crawford, & Green (2001). These units are identified by ways members of a classroom interactionally mark conversations through contextualization cues and thematic shifts (Kelly & Crawford, 1997). These events maps allowed us to situated instances of talk and action in broader patterns of social practices, detailing the overall structure of the enacted curriculum, and served as a basis to contextualize the specific discourse processes that constructed engineering (Figure 1). Through the creation of such events maps, we were able to identify engagement in engineering practices and identity work of the students and teachers.

Across the set of classroom events, we examined the transcripts for ways that engineering identity was manifested in actions and words. To do this we drew from our previous research (Cunningham & Kelly, in review), to create 16 codes of epistemic practices of engineering. These are shown in Table 2. We also identified through an iterative processes of coding, a set of emergent categories of discourses supporting identity work. These are shown in Table 3.

**Emerging patterns in identity development: Findings from interactional analyses**

Across the two teachers and classrooms, the teachers addressed and referred to the students as engineers. Both teachers did this by drawing from the available resources of the curriculum to name and identify students, actions, and practices as engineers or engineering. This naming and addressing of students as engineers become one way that students were positioned in the classrooms. This metadiscourse about themselves and their actions was also tied to sets of activities entailing the activity of engineering. Four patterns emerged in the ways that engaging in engineering fostered development of students’ views of themselves as engineers. The teachers used the introductory storybooks as a mediating tool; they tied student work to the Engineering Design Process (EDP) and characters in the stories; they built a collective sense of self through teamwork, and they recognized the students’ activities as engineering design and analysis as connection to the disciplinary knowledge and practices of engineering. This allowed students to see themselves and others in the class as engineers solving problems.

*Discourse about selves as engineers and engaged in engineering*

Both teachers made clear to their students that the class was involved in engineering. The two teachers both explicitly addressed and referred to students as “engineers,” from the first lesson and consistently throughout instruction. For example, on Day 1 in her first turn of talk, Chentel introduced the instructional unit by stating “We are going to become classroom engineers.” This naming of students as engineers continued throughout the lessons. Similarly, Jean, on her the first day of her unit in turn 5 stated “Today we are going to talk about aerospace engineering.” She continued this conversation by asking the students questions about engineers and engineering: “What do you think an aerospace engineer does?” Both Jean and Chentel sought student knowledge about engineering and revisited the role of the students as engineers throughout the units. Another example of this is found the event maps in Figure 1. In this case, the Jean’s class is working through Lesson 2. After completing working with their team to design an imaginary spacecraft that can fulfil a mission, such as collecting a sample, or taking photographs, from a celestial body (mostly planets) in our solar system. In doing so they students consider features of the body such as the temperature, atmosphere, location in the solar system, surface, and size provided to them on a data card specific to their body. With their teammates the group indicates on their worksheet which three features they will consider, why these are important, whether the spaced is manned or unmanned, and what the purpose of the mission is. They they create a sketch of their craft. After doing this, at approximately 51 minutes, the classroom conversation turned to sharing out the designs of the respective student teams. Jean sought the students’ attention, signaling a new sequence of activity by calling out to the class “Alright engineers” (turn 270). The conversation then turned to how the students’ imaginary design met the conditions imposed by the planet specific in the task for each group. Jean specified that, as part of the presentation, she wanted each group to focus the features of the body that they considered. The first group was assigned Jupiter. They shared with the group that they considered the location in the solar system, temperature, and the surface as they created their design and explain why they took these into account. One team member explained the design of the space craft in detail. They let their classmates know that the mission they chose was to take samples and that they planned to also carry people in their craft. The sequence ended with Jean noting that “And I know that some of these designs are really fantastical. And that's OK. You're thinking like an aerospace engineer and that's awesome” (turn 285).

Both teachers were clear about addressing and naming the students as engineers. This discourse provided ways for the students to begin seeing themselves as engineers. Importantly, the naming students as engineers was connected to the work of engineering. Consider the example presented in transcript 1 (Jean, Day 3, 01:32:20.2, starting at turn #578). In this lesson the class investigated the effect of various parachute variables—canopy size, canopy material, and suspension line length—on its rate of descent. Each group was assigned one variable and conducted controlled tests (three trials) for three treatments of their variable. For example, students assigned to canopy size tested canopies that were 7, 13, and 21 inches diameter. After each group collected the data, Jean invited the students to reflect upon their data with their group and make sense of them.

Transcript 1.

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 578 | Jean (teacher) | Alright. Let me give you one minute to talk with your group. Can you come up with a, can you come up with a statement about this? How does the design of the parachute affect the speed of the falling parachute? Talk about your variable and come up with an answer for: Parachutes for more slowly with.... And parachutes fall more quickly with... Alright? Come up with-I'm giving you 60 seconds to have that conversation. Go. | Teachers addresses whole class and sets the students to work on a group. |
| | | *Students begin discussions in teams. Students work on issues of drag and speed of fall.* | |
| 579 | Jean | Alright answer those questions. | |
| | | *Students continue to work in teams.* | |
| 580 | Jean | Ten seconds | |
| | | *Focus on team of Karina, Dwayne, and Neil* | |
| 581 | Karina | Done. Smaller. | To team members |
| 582 | Dwayne | What did you get for the… I got small, large | |
| 583 | Karina | Yes, cuz | |
| 584 | Dwayne | The large one, the large one. it's the biggest it caught so much drag that it fell slowly | |
| 585 | Neil | And since it is so big it caught lots of drag which make it fall so much slower. | Reading from paper. |
| 586 | Karina | Since it is biggest it can catch more air and more drag than the others. | Reading from paper. |
| 587 | Jean | OK so which one fell the fastest? | To another group |
| 588 | Jean | **Alright engineers** can I have your eyes? Can I have your eyes? | |
| 589 | Neil? | I thought it was **aerospace engineers**. | |
| 590 | Jean | Excuse me, **aerospace engineers** of course. That was a busy activity huh? So, let's see what we learned about that. About the materials with the variables that we tested. So your first, that row over there those three groups. What did you guys test? | |

In this example, the teacher, Jean, sets the students to the task of coming up with a conclusion based on the experiments they conducted of the design of the parachute on the rate of fall (turn 578). One group exchanged their respective personal understandings of the data tables they had completed as a team (turns 581-586). When Jean called the class back together, she identified them as "engineers," only to be corrected by a student "I thought it was aerospace engineers" (turn 589). This class had previously engaged with a different EiE unit that focused on bioengineering. This student’s remarks suggest that he recognizes that there are many kinds of engineers—he specifies that in this activity, they are acting as aerospace engineers. In this example, we see that students are taking up the roles and name of aerospace engineer as they learn about engineering. The connection of the disciplinary practices of engineering and identity was evident in a number of other ways leading to our second emergent pattern.

The naming of students as engineers progressed through the unit, as students began to take up the identity themselves. By day in Chentel’s class students started seeing themselves as engineers. Consider the following exchange presented in transcript 2 (Chentel, Day 3, starting at turn 744):

Transcript 2.

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 744 | Chentel | Okay, so who can be an engineer? | |
| 745 | Kathryn | Anyone. | |
| 746 | Chentel | Anyone, okay. I hope that everybody realizes that, all right? | |
| 747 | Students | Yeah. | Collective response |
| 748 | Kathryn | Even children. | |
| 749 | Chentel | Even children, so not just adults, but even children. Now, of course, if you’re an engineer as an adult, guess what? | |
| 750 | Kathryn | You know more. | |
| 751 | Chentel | Well, you will, but you also get paid to do it because you actually do it as a job. You can be an engineer as a career. You can go to college, learn more about the field, then eventually, you can spend every single day, for example, being a materials engineer working with a bunch of materials, figuring out how they go together, making new materials from existing materials, okay? It is a wealth of opportunities for people who are interested in engineering | |

The process for students to begin to recognize themselves as potentially successful in this role included more than just addressing and naming the students as engineers, they also engaged in engineering practices that provided experience for this metadiscourse, and confidence in their own abilities to engineer. We turn to these processes next.

*Teachers’ uses of curriculum and data as tools for identity development*

The teachers used aspects of the curriculum and results from experimental activity as tools for supporting students' understanding of and connection to engineering. They did this three ways: making reference to the characters in the introductory storybook, connecting students' activities to the *Engineering Design Process*, and using results of students' designs and experimental results as context for naming and taking up engineering practices.

The teachers made use of the introductory storybook to set up the engineering problem, as designed by the curriculum developers. The also built affiliation by leveraging children's experiences to create a personally relevant connection to an engineering task. Consider transcript 3 (Chentel, Day 1 (Lesson 1), [00:37:54.0], turn #s198-204). On the first day of instruction, Chentel read the book, *Yi Min's Great Wall* to the students. In the story, a rabbit gets into the school's garden and eats many of the vegetables. Chentel paused from reading the book and posed a question to the students.

Transcript 3.

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 198 | Chentel | Question for you, how do you think the kids felt when they went out to the garden and they saw that all of their plants had been destroyed again? Kadija?. | |
| 199 | Kadija | Sad. | |
| 200 | Chentel | Tell me why? | |
| 201 | Kadija | Because they must have did hard work for that garden. | |
| 202 | Chentel | They probably did. | |
| 203 | Kadija | When they figured out that it was the bunny they knew that they had do something {..} were they would hide it so the bunny would never figure out where it was so the | |
| 204 | Chentel | That's a very good point that she makes. | |

In this example, Chentel related the feelings of the protagonist, Yi Min, with the students. By relating to the emotions of the character, the students were able to empathize and understand the rationale for building a wall to protect the garden (their subsequent engineering design challenge).

A second way the teachers used the available resources to build identity was through the use of the Engineering Design Process (Ask, Imagine, Plan, Create, Improve) to view students' own activities as doing engineering through engagement in disciplinary practices. Such actions contributed to the potential development of students' agency as engineers by providing a context for discussions about what they were doing and how and why they were doing it. Consider transcript 4 (Chentel, Day 3, [02:19:20.0], turn 889).

In the third lesson, Chentel's students tested strength and stickiness of a mortar made from each earth material individually. Then they moved onto Lesson 4 which challenged the students to apply what they had learned from the tests and design a mortar using a mixture of those materials, which would be used to construct a small stone wall. Before they began their designs, Chentel asked the students to think about their classroom activities through the lens of the *Engineering Design Process (EDP)*. In this and subsequent transcripts, EPE stands for epistemic practices of engineering (with associated codes from Table 1, and ID for student identity and codes from table 2).

Transcript 4.

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 887 | Chentel | All right, so what we're going to do now is I want everyone's eyes up here on the board. I want us to take a look at our guiding question for this portion of our activity. I need volunteer with a nice clear reading voice to go ahead and read aloud. Let's go with Brianna. | |
| 888 | Brandi | How can we use the engineering design process to design a wall using rocks and mortar made of a mixture of earth materials? | |
| 889 | Chentel | Thank you Brandi. By the time we are done with today lessons we should be able to answer that question. Let's try for now. Do you think you have any ideas of how we can use the engineering design process to design a wall using rocks and mortar made of a mixture of earth material? You got some ideas for us Malcolm? | EDP named |
| 890 | Malcom | Yes, we can use engineering design process to create a system or thing for a person to ask we would ask ourselves if the material we were choosing would actually be reasonable good idea to use. For imagine we would imagine how it works and plan we would plan what we would do. | EDP - create<br>EPE: investigating materials<br><br>EDP – imagine<br>EDP - plan |
| 891 | Chentel | Okay. | |
| 892 | Malcolm | Create then you would create it. Then improve if you need to you can improve it. | EDP –create<br>EDP - improve |
| 893 | Chentel | You got a good idea there and again we'll revisit this question towards the end of the lesson. Let's talk a little bit about that story at the beginning of the week called, "Yi Min's Great Wall." Sikina, you with me? Raise your hand if you can tell me what is the process that Yi Min's grandfather suggested she used to design the wall for the garden? Yes? | |
| 894 | Raakin | The engineering design process. | |
| 895 | Chentel | Very good, thank you so much Raakin. Let's quickly review the engineering and design process. Our first step in the engineering design process is? | EDP |
| 896 | Students | Ask. | EDP – ask (collective response) |

| | | | |
|---|---|---|---|
| 897 | Chentel | Figure out what is your problem. You've got to start at that point. Next you ... | EPE: develop processes to solve problems. |
| 898 | Students | Imagine. | EDP – imagine (collective response) |
| 899 | Chentel | Imagine, so you're going to think of some solutions to your problem. It's going to involve lots and lots of brain storming. Next you are going to ... | |
| 900 | Students | Plan. | EDP – plan (collective response) |
| 901 | Chentel | A lot of planning involves drawing a diagram so you can see what it is that you want to make. Making a list as well as the materials that you're going to need then you, everyone? | EPE: envisioning solutions |
| 902 | Students | Create. | EDP – create (collective response) |
| 903 | Chentel | Create, you follow the plan that you developed in the planning stage and you create whatever it is that you're setting out to make. Then finally you'll get to a point where you ... | EDP - plan |
| 904 | Students | Improve. | EDP – improve (collective response) |
| 905 | Chentel | A lot of times boys and girls when engineers are designing new things, you know how we were testing our mortar sandwiches? Engineers will test to a point of failure. They want whatever they're making to fail. You know why they want it to keep failing and keep failing? | EPE: persisting and learning from failure |
| 906 | Kathryn | So they can improve it and make it better. | EDP - improve |
| 907 | Chentel | That's correct, that's correct. Eventually they'll get to a point where whatever it is that they're engineering or trying to make something new out of it will be the best thing possible because they worked on improving it over and over. | |

In this transcript, we see Chentel using results of students' own designs and experimental results as context for naming and taking up engineering practices. Throughout Lessons 2-4, the students engaged in a number of engineering practices to design a mortar mixture that they used to build a sturdy wall around the school garden to solve the problem of rabbits destroying the school garden. Having used the EDP as an analytical tool for identifying activities in the story as engineering practices, Chentel then shifted the focus of the analysis to the students' own classroom activities. Chentel frequently asked the students to identify the EDP step that corresponded to their current and past classroom activities. In this way, she helped her students to see their activities as engineering practices, and themselves as engineers. Consider the examples in Transcript 5 (Chentel, Day 5, [01:11:41.8], turns #701-720).

On the fifth (last) day of instruction, the students designed and tested a second mortar mixture that improved on their first design. Afterward, Chentel asked the students to reflect on their experience (701):

Transcript 5:

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 701 | Chentel | That pretty much sums up this entire experience. You guys have been the most wonderful materials engineers I have ever seen in my life, and you are only seven and eight years old, so give yourselves a pat on the back. I just want to talk to you guys, and I want you to, go ahead and refocus. | ID: naming |
| 702 | Chentel | I want you guys to think about wall design number one, and wall design number two. I need you to have a seat and just stay seated for me, okay. Did you improve your wall design from one, to two? I want you to know how you know you improved your wall design from wall one to wall two? Let's start with Javier. | EPE: assessing implications of designs<br>EDP - improve |
| 703 | Javier | I think we made it even worse because ... | |
| 704 | Chentel | The question's not about making it worse. My question was, "How do you feel you improved your wall design from one to two?" | EDP - improve |
| 705 | Javier | I think we improved it by using a different kind of mortar and we put some of the mortar on some of the sides of the rocks. | EPE: investigating materials |
| 706 | Chentel | Okay, all right. Who else would like to share with me how they felt that they improved their wall design from wall one to wall two? Yes. | |
| 707 | Raakin | For the first one more rocks fell on the design, and then on the second one, less rocks fell on that design. | EPE: assessing implications of designs |
| 708 | Chentel | Okay, yes. | |
| 709 | Jonah | We improved our wall because, at the first wall, when we did the wrecking ball, and you went to number four [inaudible 00:30:06] and the second one ... | EDP – improve<br>EPE: assessing implications of designs |
| 710 | Chentel | Go ahead and put your hands down guys, allow Jonah to speak. | |
| 711 | Jonah | ... On the second wall when we did it, we had to pass the four, had to keep going over and over on the fourth part. | EPE: assessing implications of designs |
| 712 | Chentel | Okay, was that testing part of the Engineering Design Process, was that important? | EDP |
| 713 | Students | Yes. | collective response |
| 714 | Chentel | What did it help to inform us of? Yes. | |
| 715 | Javier | If it was a good wall or a bad wall. | |
| 716 | Chentel | Then if it wasn't a good wall, what did it allow us to do? Yes. | |
| 717 | Raakin | Improve. | EDP - improve |
| 718 | Chentel | Improve, okay. Some of you definitely saw improvements, which is what you just stated to me just now. I'd like you to tell me what part, or parts of your wall did you try to improve during the second design? Yes. | |
| 719 | Kathryn | The mortar. | EPE: investigating materials |
| 720 | Chentel | Okay. Talk to me about that. | |

In this exchange with the students, Chentel, was able to weave the students' own activities as reported to her and the class through a series of interactive exchanges (702-703, 704-705, 706-709, 710-715, 716-720) with the engineering design process (EDP) (702, 704, 709, 712, 717). Through these exchanges, and making reference to the engineering practices completed by the students, the activities of the classroom were tied to engineering, thus building potential for identity development.

A final example of the patterns found in the classroom discourse concerns uses of discourse about teams to support collective sense of engineering. Through this process the students were positioned by the teacher as members of a collective working to solve a problem bigger than the work of any one student team. Across both classrooms and lessons three and four, the students worked in teams to engage with engineering practices. Consider the following examples, from a session in Lesson 3, when the students were collecting data; Jean referred to the data as a group resource that all will be generating and sharing—it's *our* data, not data that belongs to a single group or person:

> Alright *we'll*, *we'll* look at that data when we go back in the classroom. (Lesson 3, Line 459) [emphasis added]
>
> Let's get *our* data. (Lesson 3, Line 571) [emphasis added]

Upon completion of this phase of data collection in teams, the students created a data table at the front of the class. Here the data that all individual teams generated were displayed for all students to use and reflect upon. To pool the data from the measurements of fall rate of the parachutes, Jean's students needed to work together, first within groups, and then across groups, to share out data and learn about the functionality of parachutes. Consider transcript 6 (Jean, second day of Lesson 4, 00:45:06.0, turn # 606 – 626).

As mentioned previously, each group tested one possible parachute variable, and explored three treatments. To get more accurate data, the students conducted three trials. To help the groups generate common data to share with the class, Jean scaffolded her students through two calculations they needed to do. First Jean instructed them to find an average, a mean, of the drop time for their three trials. Then, they have to calculate a drop rate—they needed to divide their mean time by the standard drop distance.

Jean walked the students through these calculations so each team could report out their results to the class.

Transcript 6

| Turn # | Speaker | Talk and action | Researcher notes |
|---|---|---|---|
| 606 | Jean (teacher) | All right, all eyes up here. All eyes up here. Good. Do you guys have a mean ... Does every team ... Raise your hand if you do not have the mean of your data. Okay, all found the mean. Now you take 15 and you divide 15 by the mean. | EPE: applying math<br>EPE: working in teams<br>ID: Setting up students as team members |

| | | | |
|---|---|---|---|
| 607 | Jean | It's a little tricky for you because you're there yet mathematically that's why you have a calculator. So you take 15 and you divide it by, I don't know, 4.1 or something. You guys are just not there yet, that's okay, so that's why we have calculators. | |
| 608 | Jean | Once you have that, that is telling you how many seconds per foot your parachute falls on average. Okay? | EPE: applying math |
| 609 | Jean | Does that make sense? Look on the bottom graph, on the bottom scale. Where do we want it to be? What's a good time? Kelly? | |
| 610 | Kelly | Between 1 ... The average at 3, 1 to five, I think. | |
| 611 | Jean | So, 1 foot per second to 5 feet per second. 2.7, average, to the nearest tenth. | |
| 612 | Jean | All right, so I'm going to go team by team. And we're gonna record your average, your mean feet per second and how long are your lines and how big is your parachute canopy. Do you think that has something to do with it? | EPE: working in teams |
| 613 | Students | Yes. | Collective response |
| 614 | Jean | Okay. | |
| 615 | Sam | Because we all have the same material. | |
| 616 | Jean | I love it. Sam, say it again. | |
| 617 | Sam | We all have the same materials. | |
| 618 | Jean | What are the materials you used? | |
| 619 | Sam | Well, we used the suspension line, well the string as suspension lines. We used plastic bags as the canopy and bull clips and the load. | |
| 620 | Jean | Everybody used the same material. Why did the whole group decide on plastic as the material for your parachute? Olivia? | ID: Setting up students as team members |
| 621 | Olivia | Because it has no hole and it caught a lot of drag. | EPE: applying science |
| 622 | Jean | No holes, caught a lot of drag. So, the difference here is the size of the canopy and the suspension length size. | |
| 623 | Jean | So, let's see what happens, let's collect some data. We have 8 teams. | EPE: working in teams |
| 624 | Jean | This is the lesson that never ends. [laughs]. It's all right. | |
| 625 | Jean | It's all right, it's so good. This is good stuff. All right, okay. | |
| 626 | Jean | I want one reporter. Everybody else, close your book. Decide right now who's going to report out on the team. | EPE: working in teams |

By pooling the data, the students could observe trends and patterns that would not otherwise have been evident. Thus, all members of the class contributed to engineering understanding and improved solutions. This transcript shows Jean helping her students to understand that they needed to share their, in a consistent format, so they class could analyze it and reach understandings not only about their group's variable, but also learn about the effect of the other two variables on parachute descent. In turns 606-607 Jean walked the students through the calculations that they needed to accomplish, which were advanced for their skills. In turns 608-611, Jean helped her students to interpret the results they generated; first she did this by defining the term and then she helped the students place the number in context by asking them to situate their results on a graph of slow to fast descent. Then Jean invited the students to think a bit more about controlled tests in turns 612-622 she worked with the students to articulate which variables they held constant and which they changed. She also asked them to justify their choice of canopy materials—calling on them to link some previous explorations they conducted with their choice of material. Finally, in turns 623-626 Jean instructed each group to choose a member who would report their findings to the whole class.

*Summary of results*
The analysis of the discursive moves of the teachers to engage students in discussions about the engineering design process and related disciplinary practices supporting student work and understanding. The results show that by building on the curriculum to weave together epistemic practices of engineering with metadiscoures about students as engineers, the teachers provided ways for the students to see themselves as engaged in engineering to solve problems based on collective knowledge and activity. The students' views of engineering evolved over time, from loosely tied vicarious affiliation with an introductory storybook character to development of identities as engineers through their own solutions to a design challenges. The children in this class were encouraged to develop agency as engineers. They collected data, designed solutions, shared out and analyzed their results, and then redesigned their parachutes and wall mortar. By doing this publicly, they developed accountability to their peers and the class. Like professional engineers the students were held accountable to the criteria and constraints set forth by the curriculum and the standards of their social group. A summary (domain analysis, Spradley, 1980) of the ways of building student identity as engineers is presented in Figure 2.

## Conclusion
Engineering fields are increasingly important in society, given the needs of an expanding population and severe constraints on ecosystems. Developing human interests and abilities in solving real world problems is a major educational goal, not only of engineering, but for education more generally. As many students in the U.S. have already lost interest in science and engineering by middle school (Carlone et al., 2014; Tai, Liu, Maltese, & Fan, 2006), building success and affiliation in elementary grades provides the potential for developing informed citizens. Studies of the discourse processes of classroom life provide opportunities to examine how student identity can be developed through purposeful activity and metadiscourse about participation. The results of this study contribute to ongoing research in STEM education concerned with building access and equity, particularly from low performing school districts. The teachers sampled here were from economically diverse schools with significant numbers of students underrepresented in STEM fields. This study contributes to ongoing research in discourse and social processes around ways that academic identity can be fostered.

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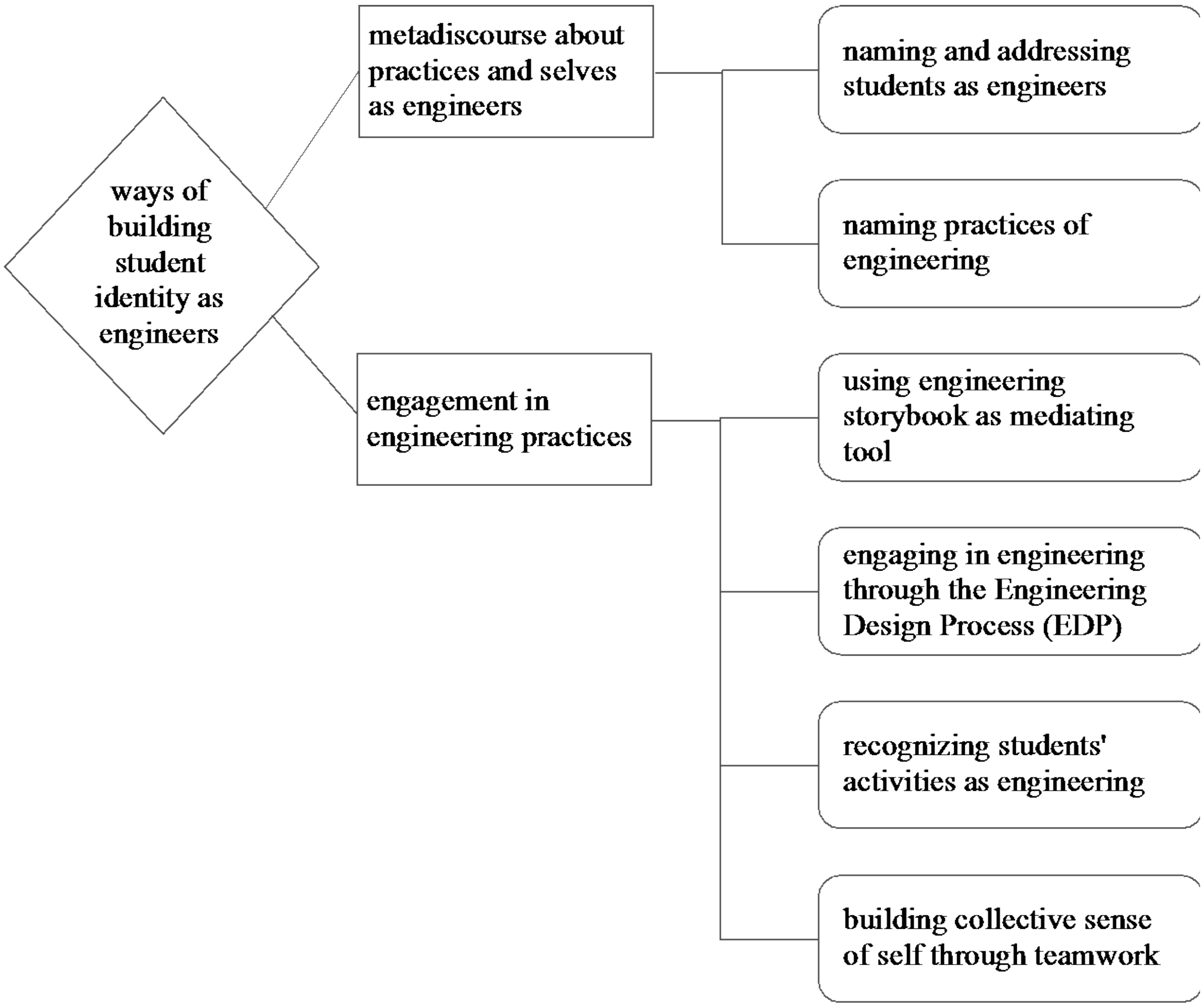
Figure 1. Sample event maps showing a representative segment of a phase unit, three sequence units and talk and action. Line 270 begins with identifying students as engineers and the final sequence ends with the teacher identifying students as thinking like aerospace engineers. Day 2 lesson focused on students designing spacecraft for missions to other celestial bodies.

| Phase units | *Time stamp* & sequence unit | Turn # | Talk and action |
|---|---|---|---|
| Presentation of student *Imagine* spacecrafts | *0:51:21.4* Setting up presentations by groups of spacecraft designs | 270 | Jean (teacher): **Alright engineers**. I saw some great. So what I'll do. I want each group to make their way up here one at a time. So when you come up bring your yellow card so I can talk about the celestial body you had and then let's talk about some of your designs. You are going to stand right up here so people can see your design, you'll hold it up and kind of explain what you did. If you all did it the same way, that's great. Explain what you decided to do and why you decided that. And if you did some things that are a little bit differently, than explain that. |
| | *0:52:01.2* Presenting spacecraft by student group: Jupiter | 271 | Jean: This team right here, Jupiter. Come on down. So when you come up and talk about it, I would love for you to say the features that you considered in your design. Features you considered in your design. I'll get out of the way. |
| | | 272 | Student: So we {} the location in the solar system, temperature and surface |
| | | 273 | Student: The surface is important to know cuz we don't want to land in any gases like the big red spot on Jupiter. The temperature was important because we don't want to freeze. And then the location is important so we don't get lost in space. |
| | | 274 | Student: So what we were thinking about it making {} that is made out of very hard materials {} lose and parts. And then what we are going to do is have this rover come out and take samples. |
| | | 275 | Student: Our idea to get the rover out. So we need two rooms. {} the people in it and this room, then open this door and the rover goes {} and then you close the door. And they have these buttons to open the door over here and the rover goes out |
| | | 276 | Student: Yeah, and you don't have to inhale any toxic fumes |
| | | 277 | Student: And when we want to get back there is another button that could put the {} a hook that pulls it back up to the room |
| | | 278 | Student: And then we have many rooms in the design |
| | | 279 | Student: These are the rooms that we designed for the ship. Like the control room that leads down to where the rover is. It's taken out. We have the bedroom. The kitchen which we decided just to into a {} and then a heating system. The stairs. The baggage area, the bathroom, the equipment and then where they {}. |
| | | 280 | Student: Oh yeah, it's gonna be manned. |
| | | 281 | Jean: Nice job |
| | | 282 | And our mission is to take samples |
| | *0:54:23.9* Summarizing student work as thinking like engineers | 283 | Jean: So since they are going to Jupiter and it is such a large space craft we talked about his team, we talk about how much what you will need, what will you need a lot of, Nathan? |
| | | 284 | Student: Fuel. |
| | | 285 | Jean: They'll need a lot of fuel, right, because it's far away. **And I know that some of these designs are really fantastical. And that's OK. You're thinking like an aerospace engineer and that's awesome.** I'm actually going to put this up so we have a blank page where we can kind of point to it. How about our next team, Jason's team. |

Figure 2. Domain analysis of ways of building student identity as engineers.



<u>Table 1</u>: EiE four lesson structure and summary for *A Long Way Down and A Sticky Situation: Designing Walls.*

| Lesson | Goal | *A Long Way Down: Designing Parachutes* | *A Sticky Situation: Designing Walls* |
|---|---|---|---|
| Preparatory | Children develop a common understanding of technology and engineering. | Pairs of children are given a simple technology (e.g., plastic spoon, paperclip) and discuss the problem it was designed to solve and the materials it's made from and why. | Pairs of children are given a simple technology (e.g., plastic spoon, paperclip) and discuss the problem it was designed to solve and the materials it's made from and why. (This lesson is constant across all units.) |
| 1: Engineering Story | Set a context for the unit, introduce the engineering challenge, and the engineering design process. | In *Paolo's Parachute Mission*, a Brazilian boy, Paolo, moves to a new town. Because of his congenital hand deformity, he is shy. An outgoing neighbor, Lucas, and the promise of home-made ice cream made with a local fruit if the boys harvest it, leads him to work with Lucas and his mother (an aerospace engineer) to apply the engineering design process and design a parachute that will float their fruit to a gentle landing. | In *Yi Min's Great Wall*, a Chinese girl, Yi Min and her friend Chen have a problem to solve—a bunny is eating the vegetables in the classroom's garden. After visiting the Great Wall and learning more about materials engineering from her grandfather, Yi Min and Chen apply the engineering design process to design and construct a wall that keeps hungry animals out of the garden. |
| 2: Broader View of an Engineering Field | Introduce a broader perspective of the featured field of engineering. Though hands-on activities students learn about the work engineering in that field do and they kind of technologies they create. | Students are assigned a celestial body (planet) in our Solar System and challenged to brainstorm the design for an imaginary spacecraft that will conduct a mission to that destination. | Students investigate the properties of how various materials including cloth, straw, brick, and paper and discusses which material is best to solve a given problem and which properties make it so. |
| 3: Scientific Data Inform Engineering Design | Students make links between science and engineering and become familiar with the materials they will use. Children collect and analyze scientific data that they will use in Lesson 4 to inform their designs. | Students conduct controlled tests of three parachute variables—canopy size, canopy materials, and suspension line length—to understand their impact on the rate at which the parachutes fall. | Students examine earth materials—soil, sand, and clay—and identify their properties. The investigate the efficacy of each as a mortar material to hold two tiles together. |
| 4: Engineering Design Challenge | Engage students in the engineering design process – Ask, Imagine, Plan, Create, Improve. | Students engineer a parachute for another planet that will meet criteria related to drop speed and size. | Students engineer a mortar mixture that will hold a rock wall together. |

Table 2. Categories of epistemic practices of engineering.

| Epistemic practices of engineering |
| --- |
| Considering problems in context |
| Envision multiple solutions |
| Innovating processes, methods, and designs |
| Making tradeoffs between criteria and constraints |
| Using systems thinking |
| Applying math knowledge to problem-solving |
| Applying science knowledge to problem-solving |
| Investigating properties and uses of materials |
| Constructing models and prototypes |
| Making evidence-based decisions |
| Persisting and learn from failure |
| Assessing implications of solutions |
| Working effectively in teams |
| Communicating effectively |
| Seeing themselves as engineers |

Table 3. Emergent categories of discourses supporting identity work.

| Categories of discourses supporting identity work | Frequency count |
| --- | --- |
| Managing expectations of student discourse | |
| Building collective sense of common effort | |
| Celebrating success publicly | |
| Setting norms for community practices | |
| Positioning students as engineers | |