Framing Engineering Practices in Elementary School Classrooms

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Engineering has entered into the K-12 reform movement in science education through *A Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013). This marked change provides new opportunities to examine disciplinary knowledge and practices, teacher discursive moves, and student knowledge, and identity formation. Engineering design potentially draws from and uses science, math, literacy, and social contexts thus may present unique interactional contexts in schools for both learners and analysts.

Elementary science curricula have faced significant challenges, including limited teacher subject matter knowledge and experience with science, and a crowding out of science due to pressure to dedicate time to higher prestige and systematically tested subject matter in reading and mathematics (Blank, 2012). Engineering education also faces these challenges, as well as the problem of teachers' lack of familiarity with engineering as a field. Nevertheless, engineering education also provides valuable opportunities for students including the application of science concepts to help solve real-world design challenges and the generation of multiple, plausible solutions that meet a set of design constraints. The paper examines how teachers and students jointly construct engineering as disciplinary knowledge and practices through participation in an *Engineering is Elementary* (EiE) instructional unit. The framing of engineering is a first step in understanding the learning opportunities afforded through engineering design challenges and embedded science concepts.

K-12 engineering education

The inclusion of engineering in K-12 curriculum and standards grew out of efforts to introduce students to concepts related to technology and the designed world. The Benchmarks for Science Literacy (AAAS, 1993), The National Science Education Standards (NRC, 1996), and the Standards for Technological Literacy (ITEA, 2000) all include recommendations for how technology concepts should be included in K-12 classrooms. Perhaps prompted by these documents, in 2002 the National Academy of Engineering began calling for the inclusion of technology and engineering in K-12 education (Pearson and Young, 2002) and has continued to convene a series of committees to study the domain and put forth recommendations (National Academy of Engineering, 2008; Katehi, Pearson, & Feder, 2009; National Academy of Engineering, 2010; Honey, Pearson, & Schweingruber, 2014).

At the turn of the 21st century, individual states also began to include engineering in their science standards (Massachusetts Department of Education, 2001). Over time, the idea of including engineering in K-12 classrooms has become more mainstream and in 2013 the Next Generation Frameworks and Science Standards included engineering. Many states also now include engineering in their state standards.

There are a number of reasons to introduce engineering concepts and practices to children. These include:

- Children are naturally inclined to tinker and create.
- Engineering and technological literacy are necessary for the 21st century.
- Engineering in school holds the promise of improving math and science achievement by making math, science, and engineering relevant to children.
- Children are capable of developing sophisticated skills and understanding in engineering at an early age.
- Engineering fosters problem-solving skills and dispositions.
- Engineering has the potential to increase student engagement, agency, and responsibility for learning.
- Learning about engineering will increase children's access to scientific and technical careers.
- Engineering has the potential to transform instruction (Lachapelle & Cunningham, 2014).

Introducing engineering into schools and classrooms should be accompanied by educational research. The National Academy of Engineering has recognized this need calling for "a research component that will provide a basis for analyzing how design ideas and practices develop in students over time and determining the classroom conditions necessary to support this development" (p. 7, Katehi et al, 2009). Although there are some studies of K-12 engineering (Apedoe, Ellefson, & Schunn, 2012; Levy, 2013; Schauble, Klopfer, & Raghavan, 1991; Silk, Schunn, & Cary, 2009), to date, none of them have a) looked at what is occurring in classrooms as the students and teachers engage in engineering activities or b) examined classroom discourse. This study gathered data in a classroom as students were engaged in engineering activities and practices to understand how they jointly constructed their experience.

Intervention: *Engineering is Elementary* (EiE) curriculum

Engineering is Elementary® (EiE) is an elementary engineering curriculum developed by the Museum of Science, Boston that fosters engineering literacy in students in grades 1-5. A core commitment of the project is to ensure that *all* children, particularly those who are underrepresented and underserved in technical fields engage in engineering (Cunningham & Lachapelle, 2014). The most widely used elementary engineering curriculum in the United States, EiE has been used by over 75,000 teachers and 7.5 million students nationwide.

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 classroom of focus in this study was engage with the EiE aerospace engineering unit, *A Long Way Down: Designing Parachutes* (EiE, 2011), designed to connect to children's study of astronomy. Table 1 summarizes the goals of each EiE lesson and provides a brief description of the activities in the *A Long Way Down* unit.

Table 1: EiE Four Lesson Structure and Summary for *A Long Way Down*

Lesson	Goal	*A Long Way Down*
Preparatory	Help 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.
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 engineering) to apply the engineering design process and design a parachute that will float their fruit to a gentle landing.
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.
3: Scientific Data Inform Engineering Design	Help 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.
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.

EiE lessons and design challenges are carefully developed so that activities invite a multiplicity of solutions – there is never a single, correct answer. Instead, students are encouraged to apply their knowledge and creativity to continually consider how they can improve the design of the technology.

Educational setting

The data for project were collected as part of a larger initiative involving the videotaping of entire EiE units in a diversity of classrooms across the nation. The schools and classrooms are selected based on (a) geographic location – about half of the classrooms are in Massachusetts and half in other states, (b) diversity – we want a diverse range of types of students, teachers, and schools, and (c) experiences – we feature novice to highly-experience educators.

School: The data were collected in an urban district in the 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.

Teacher: Jean is a Caucasian woman who had been a classroom teacher for eleven years when we collected these data. Prior to this video data collection she had collaborated as a pilot teacher for the EiE curriculum for six years, attending development meetings 3-4 times a year, piloting EiE units, providing detailed feedback about EiE activities and lessons and how they can be improved, and permitting EiE staff to observe her teaching, interview her students, and collect formative evaluation survey from her pupils. Jean piloted eleven EiE engineering units with her students. By the onset of this study, Jean was a highly skilled teacher, quite fluent in and comfortable with elementary engineering.

Students: 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's class engaged in two EiE engineering units during the school year; this study focuses on the second EiE unit the children did during this year.

Data Collection: The video data were collected as part of a larger project designed to provide documentary style footage of teachers facilitating EiE lessons. Three EiE staff members collected video and audio data that included a camera and microphone focused on the teacher, a second roving camera, and a microphone that captured the work of each group of students. All lessons of the EiE unit, A Long Way Down, were filmed in April 2012; this entailed five days of filming for a total for 5 hours 39 minutes. Before the engineering unit commenced, the videographers explained to the class that they were there to film the teacher because she was an excellent teacher and other teachers want to see how she teaches. The videographers introduced the equipment, explained what each device did and asked everyone to wave and say their name to the camera.

Research design and methodology

Our research approach is based on educational ethnography developed by Kelly and his colleagues (Kelly, 2014; Kelly & Chen, 1999; Kelly & Crawford, 1997). This approach begins by asking ethnographically oriented questions about the cultural practices of a group (Castanheira, Crawford, Dixon, & Green, 2003). In this case, we entered the analysis of the videodata set and associated classroom artifacts seeking to understand the ways that elementary engineering was interactionally accomplished among the teachers and students. To examine the ways that everyday classroom life was constructed, we drew from interactional sociolinguistics to study specific discourse processes in contexts of use (Gumperz, 1982). This research orientation is based on a set of substantive assumptions regarding cultural practices (Kelly, 2014; Kelly & Green, 1998). From this perspective, 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 come to 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. 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).

Interactional sociolinguistics begins with an initial period of ethnographic research that seeks to understand insights into local communicative ecologies, discover recurrent communicative patterns, and identity how local actors define problems (Gumperz, 2001). To familiarize ourselves with the data set, we watched the videotape of the four lessons, spanning five days and 5.6 hours. We transcribed the talk and action by speaker turn, noting the relevant gestures and actions, and coding discursive moves of each turn. Classroom conversations are episodic in nature, and following the sociolinguistic orientation, we examine the sequentially bounded units, denoted by co-occurring shifts in content, prosody, or other stylistic markers, which are represented by transcripts (Castanheira et al., 2003; Gumperz, 2001). Drawing from this perspective we identified increasingly specific demarcations in the classroom conversation by focusing on how the participants sequenced and segmented their actions. 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). These units are identified by ways members of a classroom interactionally mark conversations through contextualization cues and thematic shifts (Kelly & Crawford, 1997; Kelly, Crawford, & Green, 2001). Based in the initial ethnographic description and considering how the participants constructed events, phase, sequences, and turns, we were able to identify patterns in the ways that engineering was interactionally accomplished in this classroom. These patterns were made evidence in the construction of event maps, detailing the overall structure of the enacted curriculum, and served as a basis to contextualize the specific discourse processes that constructed engineering. Through these analyses, we were able refine our research questions, to consider the following questions:

- *How do teachers' and students' collective actions frame the take up of engineering practices?*
- *What counts as engineering, engineering design, and relevant evidence for engineering?*

As the research questions became more defined, we developed specific codes to document the ways that engineering was framed, enacted, and taken up by the participants. In each instance, the code referred to a segment of the conversation with specific beginnings and endings based on the semantics of the exchange and the contextualize cues (Gumperz, 1992). These typically spanned more than one turn, and often corresponded to the sequence unit identified previously as part of the ethnographic description.

Analysis of the social construction of parachute designs

Upon completing the event maps and transcripts following the procedures outlined above, we reviewed the discourse and actions of the classroom participants, noting the discursive moves (e.g., posing questions, revoicing student response, giving directions). We examined the transcript line by line to consider the ways that engineering was framed and taken up by the participants. Interchanges were coded identifying specific instances of classroom practices. Through this process we developed a set of codes, and applied each to the all transcript lines from Lessons 3 and 4. This was a purposeful sample: We identified Lessons 3 and 4 through the event maps (See Figure 1) as set of lessons in which students robustly engaged with science and engineering practices as they generated solutions for an engineering challenge.

A coding scheme emerged from iterations of coding and checking against previous codes. A sample of the unit of analysis for the coding is presented in Figure 2, showing the coding a transcript sample. We reviewed the codes and grouped them into three larger categories as detailed in Table 2.

Table 2: Categories, Code, and Subcodes

Category	Codes	Sub-codes
Using evidence	Modeling ways of collecting data	• Holding constant values
		• Being fair
		• Throwing out mistrials
		• Persisting in retrying samples
	Controlling a range of variables	
	Treating anomalies	
Deciding on use of data as a social process	Comparing results across groups	• Making sure data run is understood
		• Predicting results
		• Sharing results
	Analyzing data as collective	• Sharing across groups
		• Using data from class
	Using data for improved designs	• Sharing within groups
		• Sharing across groups
		• Reporting out
		• Analyzing as whole group
		• Using data for redesign
Building identity for engineering	Managing student discourse	• Building collective sense of effort
		• Celebrating success as a collective
		• Building norms for the community
	Positioning students as engineers	• Using action and naming of engineering and engineers

Based on the codes and their organization shown above, we identified three emerging patterns from data analysis of transcripts. These patterns were labeled: examining evidence – making engineering decisions with data; making sense, sharing, and comparing data; and building affinity and identity.

Examining evidence – making engineering decisions with data

Across the four lessons there is an emphasis on collecting data and using data to make engineering decisions. The teacher, Jean, was able to frame aerospace engineering as a field that is dedicated to design and redesign through principled uses of data. In this case, the ways of using data were framed and taken up as a class in particular ways. Three of the ways this was accomplished correspond to the codes modeling ways of collecting data, controlling variables, and treating anomalies.

An important feature of refining engineering designs concerns learning to control variables and use data effectively from controlled experiments. As mentioned in Table 2, during Lesson 3 of this unit the class divides into groups; multiple groups test just one of three key variables for parachute design: canopy size, suspension line length, and canopy materials. This lesson seeks, in part, to engage student groups in learning how to test relevant variables to determine their impact on the rate parachutes fall and make comparisons across groups. By assigning more than one group to a variable, the possibility of relevant comparisons materialized. Furthermore, the results of all groups becomes relevant. Because students only test one of the variables, they will need to rely on data collected and shared by their peers to understand how each the other two variables affects the parachute drop rate – they will need to draw upon this when they proceed to Lesson 4 where they manipulate all three variables and design their own parachute.

The curriculum teacher guide suggests that teachers help students recognize the need to conduct fair tests and identify how they might conduct those tests. It states:

> Explain to students that each group will examine the effect of one variable on parachute drop speed. Each group will create and test three different parachutes. They will record which parachute lands first, second, and third. Ask:
>
> - **Do you think there are any variables that we should try to keep the same for all groups?** *We should keep the load, the drop height, and the canopy shape the same.*
>
> Affirm for students that when doing experiments, it is important to only look at one variable at a time in order to clearly see the effects of changing that variables. It students have difficulty coming to this concept on their own, suggest keeping the load and drop height the same. (p.92)

The guide also outlines how the teacher could organize the testing of the parachutes:

> When testing, each student in the group will have a job. One student should hold two parachutes (one tab in each hand). The second student holds the third parachute, and the third student will check that the loads are all at the same height, and then observe the drop and note the order in which the three parachutes hit the ground.
>
> Remind students that they are interested in how each variable affects how fast the parachute falls. On their handouts, they will record which parachute lands first, second, and last. This will allow them to see how each variable affects how quickly or slowly a parachute falls. (p. 93)

Later the guide notes:

> All three parachutes should be dropped at exactly the same time. The teacher or the observing students should could down to the drop (“three, two, one, drop!”). The observing student should note which parachute landed first, second, and third, and record it on the appropriate *Testing Parachutes* sheet.
>
> If any of the parachutes experience “interference” while being dropped (gets caught on something, bumps into something etc.), the data should be discounted and all three

parachutes should be dropped again. (p. 94)

While the task is set in the curriculum, the teacher, Jean, needed to play an active role in talking through the process and the need for each group to test three dimensions of only one variable.

Line #	Speaker	Talk
145	Jean	So we have a canopy. And then the load gets clipped onto the bottom and it stays on because of that knot. It helps us keep it on. Does that make sense? Does anyone have a question so far? [no response] Good?
146		OK The size of the suspension lines are going to change. So bear with me on this one. You ready? The teams that are testing suspension lines, you will test. Suspension lines, you're strings will be 10 inches, 16 inches, and 24 inches. 10, 16, and 24. Got it?
147		Canopy material: trashbag, sheer fabric, coffee filter. Your suspension lines are all 24 inches. Got it?
148		Canopy size: You have all coffee filters and the size is a small, medium, and a large. It's like 8 or 9 inches, then 12 inches, and 14 or 16 or something like that. All of your suspension lines 24 inches long. Got it?

In this case, Jean identified the need to explain in explicit detail the variables and the procedure. The task was complicated by the fact that each of the multiple groups was testing only one of the three key variables – three different sets of tests would be occurring. The curriculum, and its enactment by Jean, did not leave the decisions of the key variables and methods for testing variables to the students or chance. Rather, by limiting the options the curriculum featured a set of variables around which subsequent discussion would focus. Thus, this portion of the learning was aimed at teaching control of variables and helping students to draw conclusions about how various parts of the parachute affected its performance. The goal was to help children develop understanding of basic principles that they could apply to their original parachutes designs in Lesson 4.

Throughout the data collection phases of the four lessons, primarily in Lessons 3 and 4, the teacher needed to model ways of collecting data. This episode below occurred during Lesson 3 about 58 minutes into the lesson. At this point the student groups have each constructed three parachutes that vary according to the variable they are testing. For example, the group that is investigating canopy size has built three parachutes – one each with an 8, 14, and 18 inch canopy. Now Jean turns her attention to helping her students orient to how they will be collecting and recording their data. Three of the members of each group will be standing at a balcony overlooking a foyer, each with one treatment of their variable. They will align the loads. The teacher will state “1, 2, 3, Drop.” And they will release the parachutes to float to the ground. The fourth member of each group, the data recorder, stands at the bottom of the foyer. As the parachutes hit the ground s/he records the order (first, second, third) on the group’s data table.

Each group conducted three trials.

Line #	Speaker	Talk
292	Jean	When we go down there, can you notice, tell me what you notice about the data collecting sheet? Linda, what do you notice about it?
293	Tanya	Like it shows different columns. Like about {}
294	Jean	Tanya?
295	Tanya	It has 3 trials
296	Jean	Three trials. We're testing each one of these materials three times. Why do you think we're not just testing it once? How come we are not just dropping it, yep, call it a day, we know it works, {} if it doesn't work. Evan?
297	Evan	Because it might not work the first time.
298	Jean	Exactly, it might not work the first time. And, not only that, you need a lot of data to make sure something is one way or another. You don't just test it once, you test it several times to be sure that you have accurate information.
299	Jean	So when we go down there, you will stand at the top of the foyer with Mrs. Francis. I'll show you were to hold it, the load on all of them, the load has to be exactly the same. So if your suspension lines are longer or shorter, the load has to be the same. You see this [demonstrates]? This is how it would drop. I'm not going to go like this with the parachute, the canopy, I want the load at the same place. Got it?

In this episode of modeling data collection, Jean explained the importance of multiple trials. Much as the control of variables, this was a teaching activity, for which the decision about whether to use trials was not at issue. Rather, through this explicit approach, students were given the opportunity to learn about the need for trials in engineering analysis. The use of multiple trials comes up throughout Lessons 3 and 4, as variables and design are put through multiple tests. This modeling of uses of data served the larger goal of learning from empirical tests through systematic analysis. This systematicity was important for many reasons, including the ways that anomalies in the data were treated.

An important feature of science and engineering research is the role of anomalous data. Treating anomalies was one of the coded categories we considered as the Jean and her students sought to make engineering decisions based on data. The following episode occurred towards the end of Lesson Four at (1:19:14) when the students were comparing data across groups on a common table presented on a flip chart. They had previously shared data across the class (see "sharing and comparing data" below) after their initial parachute designs. At this point, the discussion centered on the second, improved design, which took into account the previous designs, the data collected and compared across the groups, and the discussions about related variables. The teacher again collected the results from the student team groups, noting in a different color on the same data table the results of the "improved" student teams' designs as seen in Figure 3.

During the discussion, Navarro pointed out an anomaly in the data table (line 1218): groups 4 and 8 have the same measures for relevant variables (canopy size (18"), suspension line lengths (14"), but differ in the dependent variable of drop speed (2.3 vs. 2.7 feet per second). The teacher noted that the drop speeds are close, but then recognized that Navarro has a point about the variation in the data (lines 1219, 1221). She used this anomaly to address a broader issue about data collection posing the problem for the student about "how to get the data to be really, really close?" (line 1222). Navarro responds by noting the value of multiple data trials (line 1223).

Line #	Speaker	Talk and action
1218	Navarro	How does number 4 and number 8 have the same thing, but they have different drops [speeds]?
1219	Jean	4 and 8 have the same what? Same this? OK and different drops, but look at how close they are.
1220	Navarro	Yeah but still.
1221	Jean	Aren't they pretty close? How far away are they? 4 tenths? That's really close, that's really close. Well it should be …
1222	Jean	Navarro makes a good point. You would think it would be the same. How would we get data to be really, really close? Close to what we think?
1223	Navarro	Do it over and over.
1224	Jean	Over and over and over and over. Test and test and test and test.

In this case, the student, Navarro, pointed out the anomaly for the class. He made an important observation, which could have, and almost was, treated as a close enough to count as the same comparison. In lines 1222, Jean decided to shift the conversation and recognize the value of the observation, and redirected the conversation to the beginnings of thinking about treating random error. Navarro recognized this move and offered a process to eliminate random variation – repeated trials.

Making sense, sharing, and comparing data

A key set of practices for the classroom were the social bases for making sense of data collected about the science concepts and engineering designs, sharing within and across groups, and comparing data to draw inferences for engineering redesign. The codes contributing to the understanding of this theme of deciding on use of data as a social process were comparing results across groups, analyzing data collectively, and using data for improved designs (See Table 2).

After the children have design their own parachute in Lesson 4 (Line 351), Jean helped the children understand how they will work within their team to drop their parachute and record the resulting data—how many seconds it took for the parachute to fall.

> Listen to me. Team member. Thomas. Abby. Team member 1 is dropping it first will stay up here with the parachute. The other, listen to me very carefully, the other team members are going downstairs with your recording data. Recording sheet, Nicole. Someone needs it, whoever is with your group. Recording sheet needs to stay downstairs with your team. Got it? Team members 2 and 3 go downstairs with the recoding sheet. One of you has to go downstairs. (Lesson 4, Line 351)

Jean also continually articulated her expectation that students collect and record data not only from their own group's parachutes' descent but also those of others. For example, in Lesson 3 (Lines 333 and 334) when the groups are each testing different variables (canopy material, size, or suspension line length, Jean impressed upon her pupils that all the variables and data matter – they will need the information from all groups not only their own.

333	Student	What if someone else drops it?
334	Jean	You make observations of your own. But if you do observe something else, you do want to observe it because you need to have this information about all these variables. To build your own parachutes. Got it?

A few minutes later, she reminded them a few more times of the need to attend to the tests that other groups are running because the information from *all* the groups will help them with their designs.

> Every member of the classroom is watching these tests. (Lesson 3, Line 501)
>
> OK, everybody pay attention. This is going to matter when you guys go to design your own parachute. (Lesson 3, Line 512)
>
> You have to pay attention to every test because all these. Nicole. All these materials matter. All of them. Everything. Every variable matters. Pay attention to each team that drops and make good observations. Clear? Right now we're testing materials. Watch. (Lesson 3, Line 357)

When students are 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:

> Let's get *our* data. (Lesson 3, Line 571) [emphasis added]

> Alright *we'll, we'll* look at that data when we go back in the classroom. (Lesson 3, Line 459) [emphasis added]
>
> I want one reporter. Everybody else, close your book. Decide right now who's going to report out on the team. (Lesson 4, Line 626)
>
> Every other team member close the book. One team member has the book open, all calculators down, all pencils down. *We're* gathering data, [the results of the testing for the data table we're creating] we're going to start here and go around. Got it? (Lesson 4, Line 631) [emphasis added]

The data from the trials are not the only information that Jean expects her students to share. For almost every trial, she asked group members to publicly share their prediction about the order in which their different parachutes will land and then invites the class to reflect on the statement by agreeing or disagreeing. A typical exchange entailed:

Line #	Speaker	Talk and action
424	Jean	OK who has a prediction before they drop it? Uberto do you have a prediction before they drop it?
425	Jean	Before you drop it what plastic will be the slowest?
426	Student	I think that the plastic will be the slowest.
427	Jean	OK what do you think is going to be the second slowest?
428	Student	The paper.
429	Jean	And then
430	Student	Sheer.
431	Jean	Sheer fabric. Does anybody agree with that thinking?
432	Student 2	Yeah
433	Jean	OK.

Not only did the students share data across groups, they are also asked to compare data and are expected to use these data for collective analysis that will inform redesign. Sharing and comparing data was designed to foster a collective sense of achievement and provide an evidentiary basis for decisions about engineering design. One key part of the engineering design process is improving designs based on analysis. Most students strive to improve their designs, thus, which motivates them to attend closely to the results of their first test and what they might learn from them.

In Lesson 4, Jean helped her pupils connect data analysis and improved designs with the following statement:

> "So today, let's think about this. Before you begin to improve, before you improve, let's share our data with one another. Did all of the parachutes fall the same way? No. Were some slower that others? Let's think about why. Let's try think about why before you start to improve your parachute design. OK?" (Lesson 4, line 699).

This introduction also clearly communicates that such analysis will be undertaken as a team. Data from any one group are drawn into the collection of data relevant to the engineering designs. Jean makes it clear that all groups will share the data and reflect upon them:

> OK, ready? Attention. OK, aerospace engineers, I'm going to go team 1, 2, 3, 4, 5, 6, 7 and 8, alright? And you're going to share out your information and we're going to talk about the data that we have. (Lesson 4, Line 707)

We present two instances of how analyzing data as a collective lead to inferences about patterns in the data. In this first instance (on the third day of Lesson 4 at 0:11:35) the class has finished reporting the metrics – average drop speed, canopy size, and suspension line length – for their first designs. These were written in a class data table (see Figure 4). The class is going to analyze these data and see what they can learn to improve their parachutes during their redesigns. Jean displays all groups' data in a chart. Then she asks the children to reflect on all the data that have been collected.

To set up the type of analysis sought, Jean prompted the class:

> Alright, I want you to look at this. Can everybody see the data? Look at it for one minute and I want you to talk about with your team, what do you notice about the teams whose average drop speed was lower and all their suspension line length and the diameter of the canopy. Is there any connection or correlation between these two things and this? Look at it for a minute and then have a conversation at your group. You think there's any connection between them? Talk to your team. (Lesson 4, Line 771)

She set the groups to work, looking at the data collected across groups to make inferences about the patterns in the data.

Line #	Speaker	Talk and action
774	Jean	Alright, teams, anything you noticed? Anything you noticed at all? Wendy? What about you guys?
775	Wendy	I noticed 8 and 3 were exactly the same, like, almost.
776	Jean	8 and 3. Uberto noticed the same thing. Uberto, can you just say what you just said to me?
777	Uberto	I don't get why if we got the same canopy size and they only had

		one inch more than us for the suspension lines and it's such a difference for the average drop speed.
778	Jean	Let's talk about this. Do you remember when you built your canopy?

In this case Wendy's group noticed that two of the groups chose almost the same size canopy and suspension line length. Jean points out that another student, Uberto, had noticed the same thing and raised an important question about why such similar constructions produced such different drop speeds. Jean uses this question to launch a short conversation about the need to "test and test and test again" (Lesson 4, Line 786).

Then Jean returns to the data table and asks the students what else they noticed about patterns in the data.

Line #	Speaker	Talk and action
788	Jean	Who are you guys [which group number]?
789	Kelly	7. Ours is big and their suspension length is very big and ours is very small.
790	Jean	Okay, Olivia.
791	Olivia	This isn't really a comparison but I noticed that the people who had shorter suspension lines and bigger canopies had lower average drop speed.
792	Jean	So Olivia just said I noticed that ... can I have you, Linda, stand up? [teacher holds one of the parachutes] I don't know who this team is. Can you hold this? [gives the parachute to Linda to hold] Turn this way. [teacher picks up a second parachute and stands next to Linda] Olivia said, I noticed that ... Nor, can you say that one more time and we'll try to kindda point to it as you're talking? You have to speak loud because I can't hear you over here.
793	Olivia	I noticed that the parachutes with shorter suspension lines [teacher points to suspension lines on the parachute she is holding which are shorter than the other parachute and says "shorter"] and bigger canopies went slower and had lower average drop speed.
794	Jean	Then something with a long suspension line [points to longer suspension line of the parachute Linda is holding]. Why do you think a long... We know that long suspension lines do help you, we know that, compared to the really, really short ones. How long do you think it has to be? Do you think that long is really going to help you?

The opportunity to look across the data collected by multiple groups during the analysis allows Olivia to generate a very important conclusion about parachute design, which she share with the whole class – parachutes with shorter lines and bigger canopies fall more slowly. By inviting the children to share their thinking and thinking with the group, all students in the class can consider Olivia's observation and potentially apply the principle to their redesigns as well.

Discussion: The social nature of engineering design and learning engineering

In the classroom we studied, engineering was framed as a discipline through collective actions of the teacher and students within the constraints and affordances of curriculum and school practices. The printed curricular materials suggested some structures that encouraged collaborative work (an affordance). The rich enactment and embodiment of these principles by this teacher further supported children as they engaged in engineering practices. Curriculum is both the intended written documents that teacher and students reference but also the interactive, discursive work constructed by these class members through concerted activity. The enacted learning opportunities were made visible through careful analysis of the moment to moment interactions of the classroom.

The teacher is able to enact these learning opportunities through the affordance of the curriculum and her specific teaching practices. She did this in a number of ways. First, she develops a common focus that provides a framework that allows children to learn because they have a common experience and a shared basis for deliberation. Through her instruction, the teacher focuses her pupils on a subset of relevant variables, models standard ways the student groups will conduct tests so these data can be shared and used as a common basis for decision regarding engineering design. Once the data are collected, the teacher skillfully guides discussions about patterned and anomalous data, and structures the instructional conversations around disciplinary criteria related to engineering.

Second, the teacher takes up the curricular affordances by expecting standards procedures, materials, and data collection techniques. This allows the class members to share and compare what they have found and learn from each other. For example, her students are asked to make predictions publicly and the class is invited to comment on these. Data from each group are shared with the whole class and become common data. The teacher's expectation is that the class as a whole analyzes their data and draws conclusions. Because children publicly share their ideas and understandings, all children can use the shared insights to improve their next design; their knowledge is communal, not individual.

Finally, the children in this class are encourage to develop agency as engineers. They collect data, design solutions, share out and analyze their results, and then redesign their parachutes. By doing this publicly they have accountability to their peers and the class. Like professional engineers the students are held accountable to the criteria and constraints set forth by the curriculum and the standards of their social group.

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Figures:

Figure 1. Sample of event map from Lesson 3, showing only phase units, time stamps, and sequence units for first hour of 1h39min lesson.

Phase unit	Time stamp (hr.min.sec)	Sequence unit
Move from Imagine to Ask, set up of day's task	(0:01:37.9)	orienting to the Ask phase
	(0:02:18.3)	identifying what's needed to know to design a parachute
Testing the effect of atmosphere on falling objects (following guiding question)	(0:04:31.4)	identifying atmosphere thickness as a variable
	(0:05:07.7)	identifying models to solve scientific problems
	(0:07:02.5)	demonstrating the differences in fall rate in two atmospheres
	(0:08:29.4)	introducing food coloring to see role of atmosphere in limited falling object
	(0:09:25.5)	object pushing atmosphere as it falls
	(0:10:34.6)	revisiting guiding question about atmosphere thickness and fall rate
Introduction to the design of a parachute	(0:12:06.1)	identifying parts of a parachute
	(0:13:14.5)	identifying key variables for groupwork task
Directions for building the parachutes for group tests	(0:16:05.7)	describing ways of making the canopy
	(0:24:27.0)	describing measuring process
	(0:25:33.9)	providing details about the construction of test parachutes
	(0:27:38.4)	reviewing process for group - divergence to revisit tasks
Materials distribution and transition	(0:28:39.9)	distributing materials
	(0:31:13.5)	transitioning to small group work
Student group work on parachute variable testing designs	(0:31:43.1)	setting up materials to use to build
	(0:32:15.3)	clarifying the assignment
	(0:33:05.9)	working on parachute suspension lines in small groups
	(0:37:19.4)	clarifying how to mark for suspension lines - teacher calls whole group together
	(0:37:49.7)	working on parachute materials in small groups
Evaluation of progress on parachute construction	(0:56:38.4)	checking on data sheets
	(0:57:47.7)	checking on progress
	(0:58:36.3)	checking on procedures of trials
	(0:59:25.1)	explaining process of dropping parachutes
	(1:00:44.2)	checking for understanding of trials

Figure 2. Example of coding of transcribed talk from Lesson 4.

Time stamp	Line 3	Speaker	Talk (by turn)	Analytic codes
(0:14:54.2)	1217	Jean	Do you notice that the canopy and the suspension lines are a little bit closer in size than they were, some of them, originally? A little bit closer in range than the original ones which made them, I think, contributed to the growth, the improvement. Yes?	compdataimp
(0:15:14.6)	1218	Student:	How does number 4 and number 8 have the same thing, but they have different drops?	anomdata
	1219	Jean:	4 and 8 have the same what? Same this? OK and different drops, but look at how close they are.	
	1220	Student:	Yeah but still.	
(0:15:32.7)	1221	Jean:	Aren't they pretty close? How far away are they? 4 tenths? That's really close, that's really close. Well it should be,	
(0:15:43.0)	1222	Jean	Nathan makes a good point. You would think it would be the same. How would we get data to be really, really close? Close to what we think?	anomdata stdisc
	1223	Student:	Do it over and over.	anomdata
	1224	Jean:	Over and over and over and over. Test and test and test and test.	anomdata
(0:15:56.1)	1225	Jean:	So, round of applause for everyone, you did a fantastic job, aerospace engineers. Let's clean this up, independent reading and snack.	ideng stdisc

Sample of codes from coding dictionary:
compdataimp = comparing data for improved design. Data sharing leading to improved data designs, comparing across artifacts and different interactional spaces (within group, group reports out, whole class investigation.
anomdata = treating anomalies. Recognizing discrepancies in data patterns.
stdisc = managing student discourse. Managing expectations of student discourse about each other; this builds collective sense of effort, celebrates success with class, establishes norms for community.
ideng = identity in engineering. Identity and use of positioning students as engineers.

Figure 3: Class data table for first design and improve design

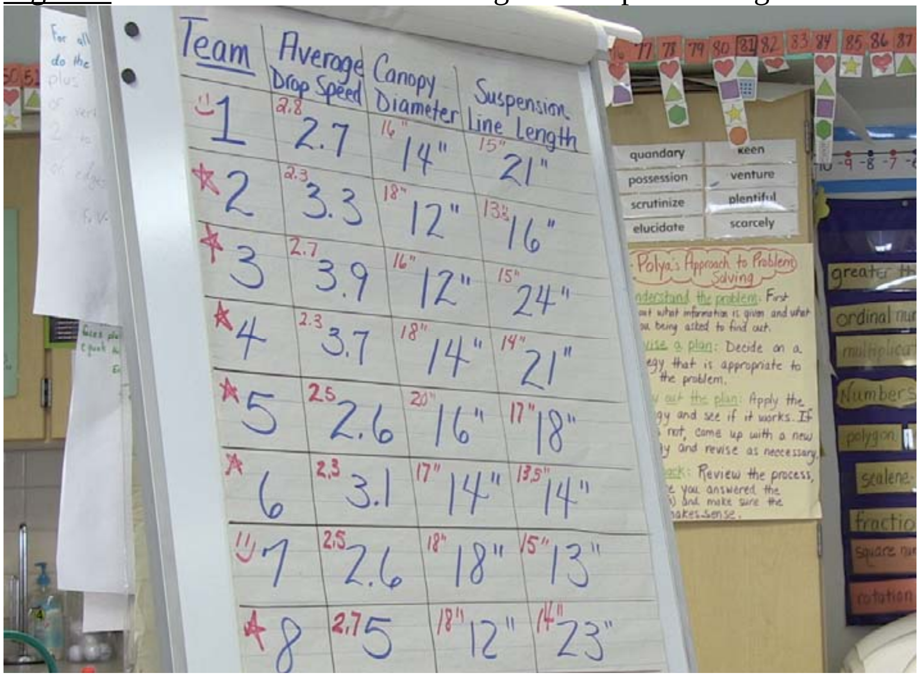

Figure 4: Class data table for first parachute design