ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15180

The Roles of Engineering Notebooks in Shaping Elementary Engineering Student Discourse and Practice (RTP)

Jonathan D. Hertel, Museum of Science

Jonathan manages the Examining the Efficacy of Engineering is Elementary (E4) project (an NSF-funded study of the efficacy of the EiE curriculum), overseeing and organizing a research effort that involves 240 teachers in the different states. He also provides evaluation support for the Engineering Adventures and Engineering Everywhere projects. He holds an Ed.M. in learning and teaching from the Harvard Graduate School of Education. In 2013-2014, he was named a CADRE Fellow as part of the NSF Community for Advancing Discovery Research in Education (CADRE) project.

Dr. Christine M. Cunningham, Museum of Science

Dr. Christine Cunningham is an educational researcher who works to make engineering and science more relevant, accessible, and understandable, especially for underserved and underrepresented populations. A vice president at the Museum of Science, Boston since 2003, she founded and directs Engineering is Elementary™, a groundbreaking project that integrates engineering concepts into elementary curriculum and teacher professional development. As of September 2014, EiE has served 6.2 million children nationwide and 71,000 educators. Cunningham has previously served as director of engineering education research at the Tufts University Center for Engineering Educational Outreach, where her work focused on integrating engineering with science, technology, and math in professional development for K-12 teachers. She also directed the Women's Experiences in College Engineering (WECE) project, the first national, longitudinal, large-scale study of the factors that support young women pursuing engineering degrees. Cunningham is a Fellow of the American Society for Engineering Education and was awarded the 2014 International Society for Design and Development in Education Prize. She holds B.A. and M.A. degrees in biology from Yale and a Ph.D. in Science Education from Cornell University.

Dr. Gregory John Kelly, Pennsylvania State University

Gregory Kelly is a Professor of Science Education and Associate Dean for Research, Outreach, and Technology in the College of Education at Penn State University. His research investigates classroom discourse, epistemology, and science learning.

Dr. Cathy P. Lachapelle, Museum of Science

Cathy Lachapelle leads the EiE team responsible for assessment and evaluation of our curricula. This includes the design and field-testing of assessment instruments and research on how children use EiE materials. Cathy is particularly interested in how collaborative interaction and scaffolded experiences with disciplinary practices help children learn science, math, and engineering. Her work on other STEM education research projects includes the national Women's Experiences in College Engineering (WECE) study. Cathy received her S.B. in cognitive science from the Massachusetts Institute of Technology and her Ph.D. in educational psychology from Stanford University.

The roles of engineering notebooks in shaping elementary engineering student discourse and practice (RTP)

Introduction

Over the past decade, engineering has steadily made its way into K-12 education; national and state standards now include engineering as a discipline that children should engage with[1]. Real-world engineering design challenges are open-ended—multiple solutions to the problem exist[2]. A challenge engineering introduces into classrooms is how classes can be structured so that they afford students the opportunity to think creatively and generate new solutions as they engage in the types of conversations and deliberations that occur in engineering teams. An engineering notebook offers one possible solution. Real engineers are often trained to use an engineering notebook to document and structure their work. Providing classroom students with a notebook offers opportunities to organize their behaviors, make reference and use of data, and structure their activities. An important goal of engineering education is to engage children in actual practices of engineering. Notebooks may be able to do this on two levels—they model the importance of recording information and, at the elementary level, can provide scaffolding that engage students in engineering practices.

Notebooking in elementary engineering education

Engineering education at the elementary level features similar pedagogies and artifacts to science education. Among these is the use of notebooks (or journals) in scientific investigation and engineering design. The methods for implementing notebooks in science and engineering classroom settings are diverse, and integrate writing and drawing, communally and individually. Regardless of the approach, the use of notebooks assumes some inherent value in affording students opportunities to write and document within a discipline-specific context. Our review of literature revealed that research focusing on how writing supports engineering learning is largely nonexistent. However, as a corollary body of work, much research has been done to examine the value of writing as discourse in science education and to scientific literacy[3,4].

In science, writing is a key method for building and distributing knowledge. The use of notebooks and other written inscriptions throughout the process of scientific investigation lead to further written documentation that become objects of discussion and peer review[5]. This is why Norris and Phillips differentiate how to write and read in science, what they call the *fundamental* sense of scientific literacy, from the knowledge of science (the *derived* sense of scientific literacy); they note, however, that within science these senses are tightly interconnected due to the importance placed on written documentation[6]. As the end product in engineering design is primarily a technological product, this connection may not be as strong between the knowledge of engineering and reading and writing about engineering, the *fundamental* sense of what could be deemed engineering literacy. However, when considering the epistemic practices of engineering[2], it is clear that the nature of engineering necessitates a certain facility with disciplinary writing, particularly in the practice of recording data from testing and utilizing it in design decisions.

Research on whether writing holds the potential to bolster disciplinary learning within science suggests that students do indeed benefit from the use of notebooks and written inscription, particularly when combined with talk between students; the Science Writing Heuristic developed by Keys et al. purposefully builds discussion and negotiation into the writing process[7]. This is reinforced by Rivard and Straw, who argue that talk combined with writing enhance retention of science learning over time[8]; talk provides opportunities to share knowledge, ask questions, and build understanding, while writing affords students prompts to refine and consolidate ideas. Problem-based learning models for science education also advocate for notebooking, particularly intentionally structured notebooks that feature more than open-ended writing space, as a form of scaffolding that makes thinking explicit and reduces cognitive load, as well as providing some form of expert guidance, whether from teachers or from curriculum developers[9]. These opportunities seem possible in the context of engineering as well. In this paper, we examine the role notebooking plays in group design activities to not only support student development of engineering practice.

Research questions

In this study we drew from a collection of video tapes of elementary classrooms implementing four different design challenges. We supplement video of a small group interacting with the written engineering notebooks students produced and the curriculum materials used by the teachers in these units. We are interested in the role of the student notebooks in the engineering design activities. In this study we pose two questions:

- In what ways do notebooks structure engineering design activities?
- What roles do the engineering notebooks play in helping student engage in engineering practices?

Educational intervention and study context

Data for this analysis were collected as part of a large-scale efficacy study of the Engineering is Elementary curriculum. Engineering is Elementary (EiE) is an elementary engineering curriculum that fosters engineering literacy in students in grades 1-5. Each of the twenty EiE units engages students in a particular field of engineering that is related to a science topic they are already learning about in school, ultimately building to a design challenge in which students experience the arc of the engineering design process and develop a technology. The efficacy study included four units:

- *An Alarming Idea: Designing Alarm Circuits*: This unit introduces students to the field of electrical engineering as they incorporate their understandings of electricity to design alarm circuits. During the design challenge, groups are tasked with developing a circuit that triggers an alarm when a trough for feeding a baby lamb is empty. Students plan a circuit design, test it themselves, and develop a schematic diagram. They pass it to another group in the class to construct and test. Based on the results, they improve their design[10].
- *A Slick Solution: Cleaning an Oil Spill:* This unit introduces students to the field of environmental engineering as they develop a process for cleaning a model oil spill and explore the effects of oil spills on ecosystems. Groups use a variety of materials as they

design and test a process to contain and remove a model oil spill. They consider the cost of the materials and their effectiveness in a second iteration[11].

- *A Stick in the Mud: Evaluating a Landscape:* This unit introduces students to field of geotechnical engineering. They are challenged to use their knowledge of erosion and landforms to make a recommendation about where to install a type of bridge called a TarPul in a village in Nepal. The design challenge asks students consider where the villagers want the bridge to be as well as the shape of the river, the types of soil, and how deep to anchor the supports for the bridge. They test a model design to failure and incorporate several criteria into their evaluation as they design an improved plan which they propose to the fictional village[12].
- *Thinking inside the Box: Designing Plant Packages:* This unit introduces students to package engineering as they utilize what they know about plants' needs to design a package to sustain and ship a plant. In the design challenge, student groups must plan and create a package design that considers basic needs of plants and functions of packages. They then improve and reevaluate this design[13].

The study recruited teachers from Massachusetts, Maryland, and North Carolina. All participating teachers received three days of professional development on the curriculum unit(s) that they would be teaching (assigned based on alignment with which science topics they reported teaching). They then implemented their assigned unit during the 2013-2014 and 2014-2015 school years. As part of this implementation, students completed all written work in an engineering notebook which was returned to the researchers when the unit was completed. The engineering notebooks were developed for the efficacy study by consolidating worksheets already included in the teacher's guides for the units and binding them with a cover and additional blank pages for drawing and writing. Although every student received a notebook, the EiE teacher guide encourages teachers at many points to have the students write as a class or in small groups and agree on common answers.

Based on interest, location, and availability, a subset of 24 video case study teachers was recruited from the larger study. The team video recorded these teachers' full implementation of the EiE unit (approximately ten or more hours of teaching). One camera was focused on the teacher, an additional camera tracked the work of a single group. Teachers and analysts worked together to select representative student groups. The camera focused on the group and their workspace, and an audio recorder was set up in the workspace to capture the students' voices.

This study focuses on four video case study classes from the 2013-2014 school year. Our data sources include the videotapes of the teacher and the student group, the student notebooks from those in the small group, and demographic information we collected about the student, teacher, and school. Because we were interested in the roles notebooks could play in engineering design, we chose one classroom from each of the four curriculum units to remove aspects that might be specific to a particular design challenge. The student groups were selected based on:

- high level of interaction with notebooks, especially in sections related to the design challenge (as determined through mostly or entirely complete notebooks and a cursory examination of group video data)
- quality of video data for the design challenge (sufficient audio quality for constructing transcripts and camera angles allowing use of notebooks to be observed)

Demographic data were collected from teachers about their students and cross-checked with information collected from students' parents and self-report. Data about the teachers for the four classes are listed in Table 1, and student groups observed are shown in Table 2.

Table 1. Dataset Teachers

Teacher	Unit	ST	School Setting	Grade	Race/Eth.	Teaching Exp.
Ms. Glenn	*An Alarming Idea*	MA	Suburb (Large)	5th	Caucasian	3 years
Ms. Richmond	*A Slick Solution*	MD	City (Small)	4th	Caucasian	13 years
Ms. Hamilton	*A Stick in the Mud*	MA	Suburb (Large)	4th	Caucasian	10 years
Ms. Holland	*Thinking Inside the Box*	MD	City (Small)	3rd	Caucasian	16 years

Table 2. Student Groups in Dataset

Student	Gender	Race/Ethnicity
Ms. Glenn—*An Alarming Idea: Designing Alarm Circuits*		
Annalise	Female	Black/African/African American
Stephanie	Female	Black/African/African American
Wai	Male	Central/Southeast/East Asian
Ms. Richmond—*A Slick Solution: Cleaning an Oil Spill*		
Emma	Female	Caucasian
Henry	Male	Caucasian
Sophie	Female	Caucasian
Ms. Hamilton—*A Stick in the Mud: Evaluating a Landscape*		
Alice	Female	Caucasian
Eleanor	Female	Multiracial
Evan	Male	Caucasian
Ms. Holland—*Thinking Inside the Box: Designing Plant Packages*		
Amy	Female	Caucasian
Grace	Female	Caucasian
Teddy	Male	Caucasian

Method of analysis

In this analysis, we adopt educational ethnography techniques developed by Kelly and his colleagues[14,15,16]. Educational ethnography examines the cultural practices of a group such as a classroom, as they interact and work together to build common ways of being[17]. For this paper, we examined classroom video and student engineering notebooks with an interest in understanding how the notebook plays a role in the engineering processes and practices of student groups. As student groups primarily utilize the notebooks not individually but to write common or consensus responses or record data from group design testing, this approach reflects the construction of their everyday classroom life. The discourse processes in which students are communicating with each other and through the notebooks necessitate contextual study; thus, we drew from interactional sociolinguistics[18]. Viewing student group and class activity as cultural practice, this orientation is based on a set of assumptions[14,19]: that classrooms have languages, norms, and expectations defined over the course of time as the members of the class affiliate, some of which become routinized and internalized, ultimately becoming the everyday ways of being. At the same time, members can reshape and reconstruct these cultural practices. This development occurs interactionally through discourse processes enacted by members of the class, all of whom bring in other cultural practices from outside groups that may mesh or clash with those of the class[19].

An interactional sociolinguistics approach to analysis starts with initial investigation that seeks insight into recurring group discourse patterns and ways of defining problems[20]. To more fully understand these aspects of the data set, we reviewed videotape of the design challenge in the 4 classrooms (in total, 16 hours of footage). We transcribed the speech of the teacher and students by speaker turn, paying specific attention to and noting gestures and action associated with the engineering notebooks. Event maps constructed from these transcripts depicted broad shifts in content or style of conversation that mark bounded units as well as logging instances in which speech and action referenced or occurred around use of the engineering notebooks[17,20]; these instances because the primary unit of observation. Analysis of the transcript led us to develop a set of in vivo codes focused on the work of the notebook in the small group conversations. Using an iterative process and reviewing our codes, we developed two larger categories for analysis. Through this ethnographic exploration of the data, we identified patterns in the usage of notebooks and the roles that notebooks came to play within and across groups and classes during the design challenges.

Findings

Through the process of examining instances of notebook usage in the transcripts of the small group interaction line by line, we developed a set of codes representing the roles that notebooks play in the students' engineering experiences, phrased as actions the notebook takes not as a mere tool but essentially as a participant in a group's discourse. We applied these codes to the transcript and revised them as we checked their persistence across the sample. Through successive iterations of the coding process, we arrived at the set depicted in Table 3. Based on these codes, we derived two primary constellations of roles. These categories are that the notebook "scaffolds student activity" and "supports epistemic practices of engineering."

Table 3. Categories and Codes

Category	Code
Scaffolds student activity	Structures teachers' lessons
	Provides reference for student decision making and consensus
	Provides prompts for students and groups to refocus their activity
	Focuses student attention on relevant details and processes
	Previews future parts of the lesson and design process
Supports epistemic practices of engineering	Prompts students to synthesize and reflect on engineering design
	Provides record of testing information for design evaluation and improvement planning
	Supports communication of ideas to other students and to teacher
	Provides visual reference for development of explanations
	Holds students accountable to plans

Findings: Scaffolds student activity

The presence and content of the notebook structure and scaffold students' activity in the classroom. Teachers rely on the notebook as a tool to remind students what they should be doing and where they are headed within the lessons. Some teachers do this to reinforce students' understanding of the engineering design process. For example, one teacher, Ms. Holland, started the engineering design process by having students look at the diagram on their notebooks, asking them “Which step of the engineering design process, which is so nicely outlined on the back of your [notebook], everybody look, which step have we hit on so far?” (Holland.PP.2). In another classroom, prior to improving their designs, Ms. Glenn opened a discussion of the value of improving their engineering designs in a similar way, asking “If you guys look at the back of your [notebooks], you see your engineering design process, right? Why do we improve?” (Glenn.AC.1879). By pointing these instances out, these teachers were able to take advantage of the steps of the design process that are embedded in the engineering notebook and could continually orient their students as to where they are and what they should be focusing on as to their progress through these steps. In other cases, teachers used the notebooks to help students consider what they will be doing next; for example, Ms. Richmond led her students into the individual brainstorming by pointing out, “You are going to look at page 31 and page 32 on your own” (Richmond.CO.455) to emphasize that they should generate their own ideas before proceeding onto group planning. In these ways, the notebook, along with the teacher guide, ***structured teachers’ lessons***.

Although individual students were each provided with a notebook, much of the work in the design challenges was done as a group. The ways that teachers used the notebooks reinforced this; when students in a group planned their design, recorded their test results, and developed improvements they were expected to reach consensus within the group. Each student documented the shared ideas in his/her notebook. This necessity for a common record pushed students to come to agreement about what to inscribe. To generate one group idea often required students to deliberate, weigh a number of ideas, and provide evidence that convinced their teammates to support their proposal. As they engaged in such discussions, students often referenced data that were provided or that they had previously logged in their notebooks. Thus, the notebook ***provided reference for student decision making and consensus***.

We see the notebook serving in this role in the following exchange (Table 4). Here, a fourth grade teacher, Ms. Richmond, referred her students to pages 41 and 42 in their notebook, which asked groups to consider further improvements to their oil spill cleaning process design. In doing so, she pointed out the actual work they should be doing (answering the questions in the notebook as a group) as well as emphasized that engineers develop multiple, improved iterations of their designs. At this point in the lesson, students had already created, tested, and improved their cleaning processes. The notebook’s questions now prompted students to again reflect upon the performance of their solution as they thought about what they might change to improve the next iteration of their design (which they would not actually create). Students in each group were required to reach a consensus regarding which parts of their oil spill process did and did not work well. They then decided which of the evaluative scores they would try to improve in the next design: the cost score, the ecosystem impact score (how much oil remained on the water after cleanup), or the shore score (how much oil ended up on the shore of the model river).

The transcript below shows that the group initially disagreed about what to write. Henry proposed a material that he believed works well—felt (line 1668). Sophie disagreed, and when Emma questioned this, Sophie restated her assertion. In line 1671, she then went on to say that “I don’t think the rubbers bands worked as well as they could have,” explaining her rationale with an observation from the testing. Emma agreed (line 1672), and the two then discussed a material that both felt worked well: cotton balls. They explained why they feel these worked well, relying on observations from their testing (lines 1681-1710), then doing the same in their discussion of what did not work well (rubber bands) (lines 1711-1718). Henry was mostly quiet throughout this and ultimately agreed with Emma and Sophie's answers, indicating that he "Got it" (line 1719). The discussion of these materials and the amount of oil that the rubber bands left behind in the water appeared to lead Henry to posit that they should be attempting to improve their "eco-impact score" (line 1722)—examination of the entries in notebooks from the group confirmed that this is the evaluative score that all of them selected.

Table 4. Richmond.CO.1666-1722

Line	Speaker	Discourse	Researcher Notes
1666	Teacher:	All right, on page 41, with your group. I'm going to come around and get the water pans that look like they're a little oily yet. Okay. Nice, detailed answers. Number one, what part of your oil spill cleaning process worked well? How do you know it worked well? Think about the three different areas that you were using to evaluate it. Did you maybe get not a lot in your indicator? Was it maybe expensive? Number two. What did not work well and how. If you were to design a third generation of this process, which score would you now look at? Maybe you want to just focus on the ecosystem impact score. Maybe you were successful in lowering that score. Is there another score now that you would like to focus on? Maybe your cost score or maybe your shore score? If the one that you selected for one, if it worked and you were able to lower that score, what would you move on to next? Or, would you stay with that one and find out? I want you to talk with your group while I come around. And I want you to work on page 42, which is the second conclusion. If we were going to do this again, which we're not, but we can pretend we're going to do it, what would you do? Check all the things that you would change. Okay?	Ms. Richmond refers the class to the notebook pages 41 and 42, going through the questions they will need to answer. The group turns to these pages in their notebook and looks at them as Ms. Richmond discusses them.
1667	Sophie:	So, what worked well?	The group starts to discuss
1668	Henry:	Felt.	
1669	Sophie:	No, I wouldn't say felt.	
1670	Emma:	You thought the felt didn't work well?	
1671	Sophie:	Not really. I don't think the rubber bands worked as well as they could have. They were sinking and letting out oil to the bottom.	
1672	Emma:	Yeah, the rubber bands didn't work as well as last time.	In the previous evaluation, they picked the rubber band as the part of their design that worked the best
1673	Sophie:	Let's say ...	Reviewing the materials in their design

At this point the group is asked to clean their desks. The teacher removes the model oil spill and asks the students to wipe down the desks to remove water and oil. The group reminds her that they also need to give her their oil spill indicator readers (a laminated sheet that acts as a tool to measure the amount of oil remaining). They do so, and the teacher reminds the class to keep their colored lanyards on as they clean up (the lanyards assisted videographers in identifying groups).			
1681	Sophie:	Okay, let's say the cotton balls. The cotton balls worked well. We're saying the cotton balls worked well.	The conversation broke briefly as the group needed to clean up their work area
1682	Henry:	She said on 42.	He is looking in the notebook between page 41 and 42
1684	Sophie:	I'm saying the cotton balls worked well because they soaked up a lot ...	Starting to write in her notebook as she talks
The group takes a break to wash their hands with paper towels from the teacher, then gathers the rest of their materials that need to be returned. They move the microphone to make sure they don't get water or oil on it as they wipe up the rest of their table, then return to their discussion.			
1708	Sophie:	We got more uses out of them	Another break as they clean up more with teacher assistance, then back to discussing
1709	*Teacher:*	*Guys, don't move.*	*To another group*
1710	Emma:	And didn't let it go out. Picked up oil, and didn't push it out. Cotton balls.	Agreeing with Sophie and writing as she talks
1711	Sophie:	So that's it. The rubber bands...	Moving to next question
1712	Sophie:	Did not work well.	
1714	Sophie:	They sank...	The whole group is writing
1715	Emma:	Yep. They sank and let out some of the oil.	
1716	Sophie:	They sank and let out...	Writing as she talks
1717	Emma:	Some of the oil.	Emma writes
1718	Sophie:	And let out some oil leaking to the bottom.	Finishing writing
1719	Henry:	Got it.	Henry has been following along and finishes writing
1720	Sophie:	And let oil sink to the bottom.	Looking at Emma's notebook
1721	Emma:	Yeah.	Finishes writing
1722	Henry:	Definitely a eco-impact score.	Circles "Ecosystem Impact Score" in notebook

Here we see the way in which the notebook ***structures teachers' lessons***, allowing Ms. Richmond to refer to it to organize her lesson and guide children's work. The need to write an answer, the *same* answer across the group, in their notebooks, meant the students were required to discuss what they thought and then agree upon what these data suggest their next step in improving their oil spill cleaning process might be. Sophie, Emma, and Henry relied on the notebook to ***provide reference for their decision making and consensus***. By asking them to focus on what did and did not work well, the questions in the notebook scaffolded the group's progress towards picking the ecosystem-impact score as what they would like to improve. Their conversation that followed this one further built upon this line of thought—in the notebook they each recorded their group decision to add more of the cotton balls that they felt worked so well to the improved design.

The notebook also played a role in getting the students quickly back to their conversation after needing to break and clean up their model oil spill (lines 1673-1681 and again lines 1684-1708); it ***provided prompts for students and groups to refocus their activity***. The students were held accountable to the task they were to accomplish by the notebook—the need to document their decisions and next steps in the notebook oriented the students to refocus on their engineering design process. Evidence of this refocusing role of the notebook was present across the four groups we studied—for example in the plant package group, Grace ended a lengthy discussion with her group about the branding on the label for their plant package by referring to the package durability results they recorded in their notebook: "Did we get a 1 or 2 on our shake test?" (Holland.PP.2260).

Teachers, too, used the notebooks to reorient students who had been sidetracked by off-topic discussions, or who had failed to record their ideas in the notebooks as they discussed them, as Ms. Glenn's teacher aide does by telling her group "So you guys need to start drawing [your alarm circuits]" (Glenn.AC.981). This scaffolding of students' activity through the need to document the outcome of concrete steps they were to accomplish allowed students to more easily return to the actual work of engineering.

In the oil spill transcript above, we also see Sophie, Emma, and Henry deliberating about the materials that are available to use in their designs. They could have considered a variety of aspects of their oil spill cleaning process, including the order in which they used these materials or the physical way that they implemented the model tools. The notebook and its questions pointed them to think about their choice of materials, and the tradeoff between their effectiveness and cost. This is an example of how the notebook ***focused student attention on relevant details and processes***. In all of the design challenges, there were many variables that students could attend to when planning and improving their designs, but the scaffolding of the notebook directed them those that are most important.

We also see how the notebook can guide students' attention in the class that worked as geotechnical engineers. After students in Ms. Hamilton's class developed and improved their plan for where to put a TarPul bridge over a river in a Nepalese village, they concluded the unit by to writing a speech or letter to the people of the village explaining their choice (Table 5). Although students could write about many of the factors that went into their decision-making process, the notebook (page 48) specifically pointed students' attention to explaining their reasoning behind the location they chose for the bridge and their recommendation for the amount of soil compaction around the bridge's supports:

> Write a persuasive speech to the village elders to explain to them why you think your selection is the best site for building the TarPul. In your speech, include the following points:
>
> - Which site you have selected.
> - Why you think this is the best location for building the TarPul.
> - The amount you recommend compacting the soil around the TarPul foundation.
> - Why you believe that this is the best amount of compaction for building the TarPul foundation.

In this way, the notebook focused the students' attention on the important aspects of the engineering at hand.

Evan and Eleanor followed the notebook's suggestion and talked through what they were writing. They referred to data stored in the notebook as they articulated the advantages and disadvantages of bridge locations and soil compaction. The conversation, and the letters they wrote in the notebook, demonstrate that these students understood the relationship between the science of the types of soil and stream's erosion of the earth and the engineering recommendations they offered about where to site the bridge.

This pair (their third group member, Alice, was absent this day) started by clarifying why the villagers' first choice of location (site D) may not be ideal when viewed through a scientific/engineering lens; Eleanor explained that a bridge at that location would be "on a river bend and will erode more" (line 783). They then make a case that this was not true of their recommended location, site E, as a bridge here "will erode less," according to Evan (line 786). Eleanor wrote that they can compact the soil at their chosen location (line 787), and Evan added that doing so meant the support poles for TarPul bridge "will be straight and strong" (line 790). To emphasize that their site E will be more effective than the villagers' choice, they also discussed and wrote about how the nature of the "rocky soil on one side and organic on the other" (line 793) at site D meant that the "TarPul will be leaning down on one side... it would not be straight enough" (line 799). This demonstrated that they understood how the types of soil affected the efficacy of supporting a TarPul pole. Returning to focus on soil compaction and its role in making looser soil more stable, Eleanor wrote that "we can compact the soil but it will not be as safe" (line 803), to which Evan adds "as safe and sturdy" (line 804).

Table 5. Hamilton.EL.781-806

Line	Speaker	Discourse	Researcher Notes
781	Eleanor:	Let's say, the site we've picked ... is only 1 site away from where you want it to be. The site you want is...	Throughout, they are both writing as they talk and finishing each others' sentences. They explain that their recommended site E is very close to the villagers' site D
782	Evan:	So from where you want it to be at?	
783	Eleanor:	Your site... The site you want is on the river ... bend. The site ... on a river bend and will erode more.	Explaining the potential erosion of the villagers' site D
784	Evan:	Yup. River bend and it will erode more.	
785	Eleanor:	So site E, we recommend is on a straight part of the river, and will erode ...	Contrasting the villager site to their recommended site
786	Evan:	Less ... and will erode less. Okay.	
787	Eleanor:	We can compact E's soil and will make the ...	Focusing on soil compaction
788	Evan:	Soil and it will make...	
789	Eleanor:	The ... pole attached to the TarPul up. The poles holding the TarPul up ...	The TarPul bridge is supported by two poles stuck into the soil.
790	Evan:	Holding the TarPul up will be straight and strong.	Focus on effects of soil compaction for the bridge

791	Eleanor:	.. and strong ... Wait I'm going to say ... So site D will fall ...	Looking quickly back in notebook to the map to confirm soil types
792	Evan:	Where you want the TarPul to be ...	
793	Eleanor:	Is on rocky soil on one side and organic on the other... your ... TarPul will be ... leaning...	Reporting soil types as a reason against the site
794	Evan:	Yeah ...	
795	Eleanor:	Diagonal ... leaning diagonally? Leaning down?	
796	Evan:	Yeah, leaning. Leaning down. Why?	Effects of soil on bridge
Break covers microphone picking up offscreen chatter from another group discussing an upcoming birthday.			
799	Eleanor:	Tarpul will be leaning down on one side ... It would not be straight enough.	Break covers another group talking offscreen.
800	Evan:	On one side ... on one side and will not be straight enough.	
801	Eleanor:	No, we will compact it but will still not be straight enough. We can compact the soil ... but	Erases previous few words to include compaction
802	Evan:	We will what?	
803	Eleanor:	We can compact the soil but it will not be as safe and ...	
804	Evan:	It will not be ... as safe and sturdy as	
805	Eleanor:	As site E ... At least that's what I'm saying.	Finishes writing
806	Evan:	Okay.	Finishes writing

We see Eleanor and Evan discuss and write about many factors that support the recommendation they made for a site. They ultimately focused on the possible problems due to erosion of their site and the villagers' alternate choice, as well as the potential for soil compaction to reinforce the sturdiness and safety of the TarPul bridge. The notebook, and in particular the prompt for the speech, ***focused their attention on relevant details*** that can help make their recommendation more persuasive. This focus helped the pair decide what should, and shouldn't, be included in their argument to the villagers about their recommended bridge site. They needed to agree on what to write, as they would be reading the speech in front of the class. Analysis of their responses in their notebook proved that they were indeed writing the exact same speech that they later gave. This common record allowed them to help their absent group member, Alice, to catch up quickly before the public presentation. Thus, once again, the notebook also serves to ***provide reference for their consensus***.

While the notebook provided teachers a way to orient students to where they should be and what they should focus on, it did not constrain students merely to what they were doing that day. The notebook contains all the lessons for the unit and thus it ***previewed future parts of the lesson and design process*** for students. In some cases, this foregrounded the arc of the engineering design process, like when Ms. Glenn told her class as they looked at their notebooks, "When we start today, we are going to start with Ask, and we are going to go through the process. Ask, Imagine, then we're going to Plan, then we'll Create and then we'll Improve." Looking at the diagram of the steps on her notebook, Annalise asked, "We're going in order?", as she strove to understand the scope of the next few days. Ms. Glenn did not disagree but focused her on the day's work as she explained, "the only step we are not doing today is Improve" (Glenn.AC.96-98). In other instances, this knowledge of future information cued students to criteria or constraints that they had not yet discussed, potentially impacting imagined ideas and decision-making. For example, even before brainstorming initial designs for their plant packages, Grace and Teddy looked ahead and found that material cost would be a factor in their engineering: “I know how much everything is!” Grace said, and Teddy responded, “Me too. I turned and I looked in the back back back back back page” (Holland.PP.143-144).

Findings: Supports epistemic practices of engineering

The use of engineering notebooks by professional engineers is commonplace—engineers are often trained to document their trials, results, and thoughts in their notebook so they can provide a record of their data and tests. In the real world, the notebooks can be called upon as a source of evidence in altercations involving intellectual property and testing results. Students’ use of a notebook can also support their engagement in epistemic practices of engineering, particularly those that focus on communication and using evidence. Epistemic practices are the ways members of a discipline communicate, assess, and legitimize the outcomes of their work[2]. In engineering, these outcomes can include knowledge that they produce, technologies they create, accepted methods for doing engineering work, and ability to satisfy clients’ needs.

In Eleanor and Evan’s exchange above, writing the speech in the notebook did not just focus them on the important factors of the design challenge, but required them to consider everything they have learned during the unit as they crafted a persuasive argument for their design. In doing so, the notebook ***prompted students to synthesize and reflect on engineering designs***. For Eleanor and Evan, this meant recalling what they now knew about erosion, soil types, soil compaction, and how these all impact the structural integrity of the TarPul bridge, using all of this as evidence for their recommendation as mentioned above. Through the work of engineering, these students engage in the epistemic practice of balancing multiple criteria and constraints and they generate a recommendation.

In their discussion about which materials worked well to clean the model oil spill, Sophie, Emma, and Henry reflected on the fact that their rubber bands were one of the best parts of their initial design but did not work at all in their improved design. Needing to reconsider their materials as they wrote a plan for a hypothetical third design, they needed to reconcile this anomaly as they decided whether they should continue to include the rubber bands or not; it prompted Sophie to think back on the design, and she realized that the disparate data might be due to how they used the rubber bands—“I think we stretched them differently” (Richmond.CO.1933). Her process of reflecting on how uncontrolled testing led to two different results for their design would not have been initiated had the group not had to determine what they would write in the notebook.

This exchange also demonstrated how the notebook ***provided a record of testing information for design evaluation and improvement planning***. This practice occurred across the design challenges and groups we studied; by holding the information from previous tests, students could remind themselves what they were thinking, particularly when the design challenge took place across multiple classroom days. The group that was engineering plant packages found that their improved plant package design received the same overall score as their initial design. They were initially at a loss as to how they could potentially increase this score. However, as she looked back at her notebook, Amy reminded the group that they were actually thinking they could get a better score if they altered the soda bottle that was the base of their package, reporting that “we wanted to change the way it was cut," a process that would have necessitated teacher assistance and approval (Hamilton.PP.1401).

The work that students did in the notebook across the design challenges ***supported communication of ideas to other students and to teachers***. Some challenges featured more formalized communication and presentations like the one that Eleanor and Evan prepared for, but the notebooks of all of the challenges featured a section where students needed to draw individual designs and then discuss their strengths and weaknesses as they to develop a singular group plan. The design of the notebook here supported and invited communication between students. First, the notebook asked all students to brainstorm and document their individual ideas—each student had the opportunity to think creatively and capture his/her ideas at his/her own pace. Next students needed to generate a single, initial idea about the design of their technology. To do this students shared their individual ideas and thoughts with their group. They needed to figure out how to explain the features of their own challenges to other group members in words or by referencing the models and sketches they had drawn.

We see the interplay between one's own ideas, captured in notebook sketches, and a group plan in the group doing the electrical engineering challenge. Annalise, Stephanie, and Wai brainstormed their own ideas for an alarm circuit (Table 6). They now needed to coalesce these into a group plan in the form of a schematic diagram that represented the group's circuit. Supported by the teacher aide, Stephanie and Wai discussed where to put the lightbulb on the drawing (lines 1002-1004). The group addressed the fact that their current proposed design has two batteries and may have the potential to start a fire if this overpowers the circuit (lines 1005-1015). They opted to remove the battery and accepted that, as Annalise says, "we don't have to use all our tools" (line 1017). Annalise expressed confusion about where to put the foil in the design (lines 1019-1020). They then encountered an issue of whether the symbols they were using are accurate across the group, with Stephanie telling Wai that his drawing was incorrect leading him to alter it (lines 1021-1023). Wai helped Annalise understand how the wires should be put into the design by indicating on the drawing in her notebook, which helped communicate his idea (lines 1026-1030), and which was reinforced by the teacher aide (lines 1031-1032). The aide then asked the group about connecting the wires for the switch that they needed to incorporate, once again referring to their drawings (lines 1033-1035). Wai quickly developed a physical model using two nearby rules to help get his idea across, dropping one of the rulers to touch the other one and saying "Annalise, pretend these are two wires, right? When it falls down, it touches like this" (line 1036). By the end, with the help of the schematic diagrams they created in their notebooks, everyone had come to consensus and they returned to the issue of where to put the lightbulb in the design (lines 1040-1042).

Table 6. Glenn.AC.1002-1042

Line	Speaker	Discourse	Researcher Notes
1002	Stephanie:	Let me ask you something. Where are we going to put the light bulb? Where are we going to put the light bulb?	Stephanie pushes on Wai's initial plan for a circuit and points to her drawing.
1003	Wai:	I don't know.	
1004	Stephanie:	I'll just put it right here. The light bulb goes right here.	She picks a spot in her diagram and draws the bulb

1005	Aide:	We have to make sure that we only ... We don't start a fire.	Students were warned earlier about short circuits and fires
1006	Annalise:	Oh yeah we have to make sure we don't start a fire.	
1007	Wai:	How about only one battery?	
1008	Aide:	Oh this is for the schematic drawing. The foil and stuff goes on here. That's okay. You can draw around it.	The aide points to indicate that Annalise has drawn her diagram in the wrong spot on the notebook
1009	Wai:	How about only one battery?	
1010	Aide:	Yes. Why is that Wai?	
1011	Annalise:	The foil goes here.	Annalise is drawing the schematic diagram that incorporates materials like foil, not just wires
1012	Stephanie:	But we have two batteries.	Looking at her diagram
1013	Aide:	Listen to Wai.	
1014	Wai:	We can use one. Because if we use two we might start a fire because there is too much power going around.	
1015	Aide:	Because look at this. How you guys had that ...	Pointing to diagram
1016	Wai:	Like we don't have to use all of it.	
1017	Annalise:	We don't have to use all our tools.	
1018	Aide:	Right.	
1019	Annalise:	So we put the foil thing, then after that ...	Pointing to her notebook
1020	Annalise:	But how? How?	Looking at her diagram in confusion and speaking to the group
1021	Stephanie:	You're not supposed to draw it like that.	Indicating Wai's representation of the foil
1022	Wai:	Like this.	He adds a mark
1023	Annalise:	Oh that. Okay. The clip. Clip. Okay. I don't know, we don't need that.	Drawing
1024	Wai:	Yeah we don't need that.	
1025	Annalise:	Then after that we put ...	
1026	Wai:	Two. Like the two wires on the bottom stay here and when they go down they touch.	He indicates on his drawing and the others copy it down
1027	Annalise:	Wire. Wire where? Where does the wire go?	As she draws
1028	Wai:	Two wires ... And two wires.	He leans over and points on Annalise's drawing
1029	Annalise:	Oh two wires here?	Pointing at the spot on her drawing
1030	Wai:	Yeah.	Nodding
1031	Aide:	You can connect it.	
1032	Wai:	Yeah.	
1033	Aide:	So where are you going to connect the wire?	
1034	Annalise:	Connect the wire to the what?	
1035	Aide:	How is the ... What is this going to touch?	Pointing to Annalise's diagram

1036	Wai:	The wire. Pretend ... Annalise, pretend these are two wires, right? When it's fall down, it touches like this.	He holds up two rules to visualize the switch mechanism
1037	Annalise:	And then the thing lights up.	
1038	Wai:	Yeah.	The others are drawing
1039	Aide:	Okay.	
1040	Annalise:	Where is the light bulb going to go?	
1041	Wai:	Anywhere. I don't know.	
1042	Annalise:	Light bulb ... It's like a mushroom. A mushroom bulb.	Describing the lightbulb symbol as she draws

The critical role of the notebook in holding students' graphical ideas was made clear in this episode. Because they documented their ideas in concrete drawings, the students were able to refer to these to help clarify their thinking and communication as they work through the elements of their design. The need to settle upon one group idea meant that Wai, Annalise, and Stephanie needed to communicate with each other to understand the design that they were jointly proposing. The notebook ***supported communication of ideas to other students*** and, in this case, also to the teacher aide. The abstract nature of the design, as communicated through schematic diagram, however, also meant that the drawings were integral to this communication strategy. Without the notebooks, Wai would have been unable to get his thoughts across; he pointed to the drawings of his group members to explain his idea—when this was not enough he reverted to using rulers to depict motion. The notebook did not merely support communication, but specifically ***provided visual reference for development of explanations***. When showing their individual ideas for plant package designs, Amy's group also relied on their drawings to explain; her description of her idea incorporated the visual aid of her sketch. After she explained, pieces of her sketch were incorporated into the shared group design (Holland.PP.390). In these instances, communication and use of symbols are epistemic practices that engineers routinely rely upon to move forward with their design.

In the process of writing down their plans to communicate to their group and to their teacher, the students were also committing to a specific plan that they would test. They needed to be clear in their description, because by agreeing to a group plan and documenting it, the notebook could ***hold students accountable to plans***. Once a "final" design was agreed upon, students were expected to stick with it throughout the entire testing cycle. A natural instinct of students is to tinker should the design show the possibility of failure; however, this does not permit accurate data collection and analysis. By anchoring students in one design at a time, children can undertake analysis and then generate revisions to improve their design. In the alarm circuit unit, students developed a plan that is handed off to another group to design and test, just as technologies are often created in the real-world. This division of labor reinforced the need to work according to the specifications so all groups were clear on what was expected, constructed, and tested.

The importance of sticking with the plan was also experienced by the plant package group. During their initial testing, Emma, Henry, and Sophie improvised on the plan they put forth, which resulted in them far exceeding their budget due to repeated use of some costly materials (Table 7). In their improved design, Sophie diligently and repeatedly checked their plan as they tested to ensure this didn't happen again, even when Henry wanted to add a second rubber band that was not included in their plans. Henry suggested this (line 1522), but Sophie pushed back, referring them to the plan (line 1523). While Sophie prepared to test a cotton ball, the next item in their plan, Emma and Henry were distracted by potentially improvising with the felt (lines 1524-1530). Catching wind of this, Sophie once again pushed the group to stick to the plan they wrote down (line 1531). While Emma seemed to remember a plan involving folded felt (line 1532), the notebook provided Sophie with the evidence she needed to keep them on track (line 1533).

Table 7. Richmond.CO.1522-1533

Line	Speaker	Discourse	Researcher Notes
1522	Henry:	We need the other rubber band. We need to use the other rubber band.	
1523	Sophie:	No, we said we would do that earlier. We can't do it now.	Checking the plan in her notebook
1524	Emma:	Yeah, we have to take it out and see. Where is it?	Referring to the felt, which is one of the next materials
1525	Sophie:	I don't know.	
1526	Henry:	Oh, here it is.	
1527	Sophie:	Don't use the felt yet. We're not going to be able to use the felt yet. Okay? All right, first, let's do this. What I'm going to do is I'm going to go down, one, and to make it touch the bottom.	Prepares to test using a cotton ball, the next material in their process
1528	Henry:	Just clip that off.	To Emma as she prepares the next material
1529	Sophie:	Ready? One.	Testing
1530	Emma:	Well, we can use the felt.	
1531	Sophie:	Wait, what did we say to do?	Reminding the group to stick to the plan
1532	Emma:	We said we would fold ...	Not looking at notebook
1533	Sophie:	No, we didn't say we would fold it.	Looking at her notebook

Without the notebook and the documentation of group decisions that were reached, Sophie would not have been able to direct the group to refrain from improvising and repeating the cycle of exceeding their budget by adding costly uses of materials to their process. The notebook ***held the group accountable to their plan*** and thus supported the students' engineering design practice. It also allowed them more accurately use the results of their testing by ***providing a record of testing information for improvement planning*** that the group later referenced while debating which of the materials did and did not work well.

Discussion

Our careful analysis of students' interactions across four engineering challenges surfaced a number of roles student notebooking played to support student engagement in engineering. Both students and teachers used the notebooks to scaffold student activity; it provided prompts and structure to organize and order the activities of the students. As it did so, it also asked students to engage in some of the epistemic practices of engineering such as synthesizing multiple types of data to inform a design, recording and reflecting upon data, holding students accountable to their data and plans, and communicating recommendations to a client.

Engineers' notebooks are blank books. Understanding what to put into these is a practice that is built through apprenticeship and experience. Students need scaffolds to organize their activity and draw their attention to salient features. In addition, young writers often need explicit prompts to organize their ideas. With this in mind, engineering notebooks were developed for each of these design challenges. The hope was that these notebooks would take on some of the instructional load of the teacher as the multiple groups all explored a wide variety of possible design solutions. That is, by providing data tables, asking them to record certain types of data, comparing the results of their individual designs, requiring they reflect upon their data and draw conclusions, and mandating that they reach a group consensus which they record before proceeding to the next activity we hoped to scaffold student activity and interaction. Our video analysis of the student group and their work with notebooking demonstrates how the notebooks took on a role as a group member, not just a tool but essentially a participant in the discourse, by guiding student activity. The prompts provided by the notebook afforded students opportunity to discuss, deliberate, use evidence, and explain their thinking. These sorts of interactions, which are invisible in the physical artifact of the notebook, become apparent as the videos of students at work are analyzed.

While the intentional design and structuring of the notebooks studied may limit possible research conclusions, we found the development of engineering practices surfacing across classrooms participating in different challenges from diverse fields of engineering. Further research into how student notebooking in other design challenges can show and support development of engineering practice would be fruitful. As engineering becomes a more common discipline in elementary classrooms, it is essential that we gain a better understanding of how to structure design challenges, through the use of engineering notebooks and other strategies and artifacts, that successfully engaging students in authentic engineering practice.

Bibilography

[1] NGSS Lead States. (2013). *Next Generation Science Standards: For states, By states*. Washington, DC: The National Academies Press. Retrieved from http://www.nextgenscience.org/

[2] Cunningham, C. M., & Kelly, G. J. (in review). Epistemic practices of engineering in education. *Science Education*.

[3] Hand, B., Prain, V., Lawrence, C., & Yore, L. D. (1999). A Writing in Science Framework Designed to Enhance Science Literacy. *International Journal of Science Education*, *21*(10), 1021–35.

[4] Kelly, G. J. (2007). Discourse in science classrooms. *Handbook of Research on Science Education*, 443–469.

[5] Latour, B., & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts*. Princeton, NJ: Princeton University Press.

[6] Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240.

[7] Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as a tool for learning from laboratory investigations in secondary science. *Journal of Research in Science Teaching*, *36*(10), 1065–1084.

[8] Rivard, L. P., & Straw, S. B. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education*, *84*(5), 566–593.

[9] Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, *42*(2), 99–107.

[10] Engineering is Elementary. (2011a). *An Alarming Idea: Designing Alarm Circuits*. Boston, MA: Museum of Science, Boston.

[11] Engineering is Elementary. (2011b). *A Slick Solution: Cleaning an Oil Spill*. Boston, MA: Museum of Science, Boston.

[12] Engineering is Elementary. (2011c). *A Stick in the Mud: Evaluating a Landscape*. Boston, MA: Museum of Science, Boston.

[13] Engineering is Elementary. (2011d). *Thinking Inside the Box: Designing Plant Packages*. Boston, MA: Museum of Science, Boston.

[14] Kelly, G. J. (2014). Analyzing Classroom Activities: Theoretical and Methodological Considerations. In *Topics and Trends in Current Science Education* (pp. 353–368). Springer Netherlands.

[15] Kelly, G. J., & Chen, C. (1999). The sound of music: Constructing science as sociocultural practices through oral and written discourse. *Journal of Research in Science Teaching*, *36*(8), 883–915.

[16] Kelly, G. J., & Crawford, T. (1997). An ethnographic investigation of the discourse processes of school science. *Science Education*, *81*(5), 533–559.

[17] Castanheira, M. L., Crawford, T., Dixon, C. N., & Green, J. L. (2001). Interactional ethnography: An approach to studying the social construction of literate practices. *Linguistics and Education*, *11*(4), 353–400.

[18] Gumperz, J. J. (1982). *Discourse strategies* (Vol. 1). Cambridge, UK: Cambridge University Press.

[19] Kelly, G. J., & Green, J. (1998). The social nature of knowing: Toward a sociocultural perspective on conceptual change and knowledge construction. *Perspectives on Conceptual Change: Multiple Ways to Understand Knowing and Learning in a Complex World*, 145–181.

[20] Gumperz, J. J. (2001). Interactional sociolinguistics: a personal perspective. In D. Schiffrin, D. Tannen, & H. E. Hamilton (Eds.), *The Handbook of Discourse Analysis*. John Wiley & Sons.