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The influence of notebooks on elementary teachers engaging in engineering practices (Fundamental)

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Introduction

For the past ten years, STEM education reform documents have prioritized two aspects that are new to all K-12 teachers, but particularly elementary generalists. The *Framework for K-12 Science Education* [1] and *Next Generation Science Standards (NGSS)* [1] were the first time national reform documents referred specifically to engineering. Despite the number of positive outcomes to using an engineering first approach, like decreasing cognitive load, increasing motivation and engagement, shifting authority from teacher to students and other stakeholders, and valuing and showing the productivity of failure [2], it has proven to be a difficult transition. An entire workforce of teachers has matriculated through teacher education programs without experiencing or learning how to teach engineering in the classroom.

Even for those who have experience with teaching inquiry-based science, the idea of engagement in *science and engineering practices* is also new. The *Framework* and *NGSS* suggests there are eight such practices, most of which overlap between science and engineering [1], [3]. However, some have argued that engineering has practices that are both important to engineering and generative in the classroom [2], [4], [5]. Our group has reported on investigations looking closely at several of these [6]–[8].

To effectively engage elementary students in engineering practices to learn disciplinary content and crosscutting concepts, high-quality curriculum needs to be available and accessible to all, and teachers need to participate in professional learning opportunities. Those learning opportunities should not only include them as learners experiencing engineering as a novice but should also include pedagogies that are effective for scaffolding design projects and supporting students through the process of asking, planning, creating, testing, and improving. One of those interventions that has the potential for scaffolding engagement in the practices and the engineering design process is the engineering notebook. One paper described how the notebook was helpful for elementary students to break down complex problems more cognitively accessible [9]. However, we are interested more in the teacher education aspect of engineering education and are interested in how in-service teacher educators interact with engineering notebooks. The primary difference is that notebooks are required by teachers to be turned in; however, teachers in a workshop setting do not have similar requirements. So this study describes our investigation into how teachers interact with engineering notebooks as they engage in a classroom engineering activity.

Learning and Teaching Engineering

Our epistemology is sociocultural, and we view K-12 classrooms as a complex cultural setting. From a pragmatic perspective, ordinary classroom engineering activities are navigated by students in small groups that collectively use epistemological judgments [10]. While it is almost certain students will learn through participation in any classroom activity, they will not always learn what the teacher intends, so the interesting problems to research are the directions that learning takes (Lundqvist & Ostman, 2009). Current elementary engineering education reforms promote engaging students in epistemic practices [11] or the habits of mind [12], [13]. These practices, based on disciplinary work, are the ways social groups propose, communicate, justify, assess, and legitimize knowledge claims [11], [14]. Using empirical studies of engineering across disciplines, Cunningham and Kelly [4] identified sixteen epistemic practices of engineers that are important to consider for K-12 classroom engineering projects, and they have been incorporated as habits of mind of engineers for practitioners in Cunningham [12]. It is the participation in these practices that gives us insight into how students (and teachers) learn about engineering.

K-12 Teacher Professional Learning

Sustained professional development is the most effective type for fostering teacher learning and changes in teacher practice [15]–[17]. However, while a high percentage of teachers participate in professional development (PD) [18], most rural districts do not fund long-term, discipline-specific and sustained PD programs, attributed to their expense and concerns about teachers missing class for trainings [19]. While several recent studies report on PD programs, only two of 44 reviewed by Van Driel and his colleagues were focused on elementary teachers [20].

According to Loucks-Horsley [17], effective PD is 1) designed to address student learning goals and needs; 2) driven by a well-defined image of effective classroom learning and teaching; 3) designed to provide opportunities for teachers to build their content and pedagogical content knowledge; 4) supportive of teachers development of professional expertise, 5) linked to other parts of the educational system; and, 6) continuously evaluated and improved. These factors require long-term engagement with the participating teachers, and a blended approach of face-to-face and online learning has been facilitated by our colleague at CSATS [21].

Specific to K-12 engineering PD, there is not a clear description of the knowledge and skills needed for teaching engineering, in part due to the ways that states certify teachers—the majority of engineering teachers are trained as science or technology educators and few have engineering experience [13]. Neither national STEM education reforms (e.g., [1], [3], [22] nor those from the state-level [23]) will improve the education system alone, so high-quality engineering PD experiences are essential for improving K-12 STEM education [24].

Theoretical Framework

We view teachers learning in workshop settings through a sociocultural lens. Since it relates to engaging in engineering practices, we use engineering studies (studies of engineers doing their work). The materials in engineering activities are an important character in the discourse and therefore important to consider, and teachers also gain professional vision through workshops, which is an integral construct for us as analysts.

Engineering studies help us think about engineering practices. Knowledge-building (epistemic) practices are socially constructed, situated in on-going concerted activity, rely on prior discourse or artifacts, and are consequential for what counts as knowledge [14]. We can study these practices *in situ*, looking closely at the ways people doing engineering interact to accomplish their goals [25]. Engineers use their past and perceived futures to do their best understanding of high-quality engineering work [26], and the solutions they develop are directly related to these beliefs and assumptions [27].

Consistent with our overall sociocultural approach to the study of engineering education is sociomaterialism. Sociomaterialism views both the social components and the artifacts used as equally important to consider [28]. In engineering work, the people and the materials are inseparable and should be studied in this way [29]. Styre and his colleagues [28] assert that engineering accomplishment always derives from the capacity to identify and overcome failure, and relies on the *feedback*, which is intentionally derived, and *backtalk* from the artifacts, which can be unexpected [30]. It is also important to view classroom engineers using the concept of sociomaterial bricolage [25] because they are necessarily constrained by the materials with which they have to develop solutions, and as bricoleurs must make do with what they have

(Levi-Strauss, 1966). Our analyses focus on the teachers interactions with each other, with the instructor, and with the materials they utilize.

Research Questions

1. How do the engineering notebooks scaffold the teachers' activities and discourse?
2. How and to what extent does the notebook support their engagement in engineering practices?

Educational Intervention and Study Context

Data for this study were collected as a part of a funded research project that seeks to understand how rural elementary classroom teachers learn engineering content and practices through professional learning experiences and how a subset of them take those experiences into their classroom. Over the course of three years, teachers from rural school districts serving the epistemic practices of engineering [4] through participation in classroom engineering activities, reflecting on them using both their "student hat" (as a learner) and "teachers hat" (as a teacher) [32], and through learning the specific engineering units they will teach. In this case, we use the Youth Engineering Solutions (YES) for Elementary [4].

The idea of engaging in the practices of experts, particularly in a field like engineering that is mostly unfamiliar to teachers, we begin the workshop with a classroom engineering activity. In this case, we used *Perspiring Penguins* [33] because it provides opportunities to highlight some of the practices essential to engineering design and uncommon in classroom teaching. We have written in the past about practices like *balancing tradeoffs* and *persisting and learning from failure* [5], [8].

The activity *Perspiring Penguins* described in Schnittka and Bell [33] was intended studied for its ability to help improve middle school students' conceptions about thermal energy and heat transfer through an engineering design activity. This study was done prior to the description of the 8 science and engineering practices in *Framework for K-12 Science Education* [3] and the 16 epistemic (knowledge-creating) practices of engineering [4]. However, this activity is a reasonably simple activity that requires engagement in these practices to achieve the lesson objectives.

The lesson begins with a problem: a zoo in a hot climate needs to build an enclosure for a penguin to protect it from the sun while still being able to be viewed by the patrons. In this case, the “penguin” is a penguin-shaped ice cube, and the zoo is a box with heat lamps. The enclosure must start with a clear plastic deli container and participants must choose from several materials to include in their design. The materials have differing costs, with the materials that reflect heat (aluminum foil, white construction paper) are more expensive than materials that absorb or transmit heat (black foam, wax paper).

Prior to participants designing their enclosures, the instructor discusses the main scientific concepts typically taught in middle schools that they should use in considering their designs. The first is energy transfer. The heat from the lamps will be transmitted through the air by radiation and by direct contact through conduction. Simultaneously, convection will cause warmer air to rise, forcing cooler air toward the bottom. The second concept has to do with how radiation interacts when it hits a solid. It may reflect (e.g., aluminum foil), it may be absorbed (e.g. black foam), or it may be transmitted (e.g. transparent film). Teachers were then given several minutes to investigate how these materials interacted with heat by giving them a sample of each material, a heat lamp, and an infrared thermometer.

Teacher designs were evaluated on two criteria: cost and percent loss of the penguin (i.e., the mass of the ice cube before and after 5 minutes in the heat box). Multi-objective solutions like where a tradeoff between two criteria is critical to the design process. A very inexpensive solution likely will lead to significant penguin loss; a solution that protects the penguin likely takes many materials. The number of “optimal” designs can be represented as a Pareto front (Figure 1).

Figure 1 - This Pareto front diagram shows the theoretical range of designs. The stated goal in this project was to be as close to the "knee" of the curve as possible.

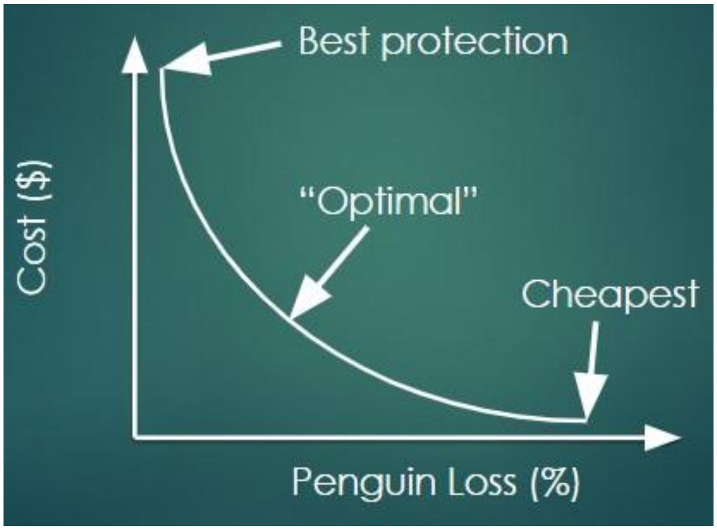

Figure 1 - This Pareto front diagram shows the theoretical range of designs. The stated goal of the project was to be as close to the "knee" of the curve as possible

In this workshop, the stated goal is to minimize both cost and Penguin loss. This theoretical score would be at the “knee” of the curve. In this arrangement, any of the 2nd designs that moved toward the knee of the graph would be considered an improvement.

The agendas of both workshops were the same for day one. *Perspiring Penguins* was used as an anchoring experience for all participants. We then reflected on those activities they engaged in to introduce the idea of “practices” and the overall phases of the activity as the *engineering design process*, using the framework used by YES for Elementary [4]. We then used local examples of engineering and technology provided by the teachers as digital photographs prior to the start and talked about how those examples could be used with their students. We then set up centers describing typical teaching they might find while teaching engineering, like running out of time to do a redesign, overly competitive students, etc. The last discussion was about failure, the types of feedback teachers often give when designs fail, and the effect on student work (Author, 2019). One the second day, the second-grade teachers learned about and reflected on the YES Engineering Pollinators unit; the fourth grade teachers learned about and reflected on the Engineering Safety Vests unit.

Participants

Two two-day workshops were held, each held for all the grade-level teachers at Athens Area School District. We had the capacity to have more teachers in attendance, so four teachers from two other rural school districts attended. Athens Area School District has two elementary schools, with a total of approximately 125 students per grade. Two teachers from Pike Elementary School (50 students/grade) and two teachers from Dahoga Elementary School (70 students/grade) also attended the second-grade workshop. The second workshop was attended by all six fourth grade teachers from Athens Area School District.

Table 1 - The participants described in this study

Group	Grade 2 Workshop	Grade 4 Workshop
Table 1	Bea	Willa
	Barrie	Jared
	Kim	
Table 2	Daryll	Christy
	Angie	Vivica
	Taylor	

Data from ten teachers who worked in four small groups at our workshop series were analyzed (Table 1). They were chosen for both theoretical and convenience reasons. Bea, Willa, and Vivica have been considered “case study teachers” throughout the grant-funded project. They were chosen because they all had attended the same rural school they teach at, had at least five years of teaching experience, and had not taught engineering prior to the start of the project. This was the second time they had attended a workshop about how to teach a YES for Elementary unit – the first time they learned the *Problem with Plastics* unit. The other teachers chose to work in small groups with the case study teachers and were included, except the group of Daryll, Angie and Taylor. They sat at a table that made it easy to video record so that group was included.

The lead instructor is the lead of the research project and lead author of this manuscript. He was assisted in the planning, implementation, data analysis, and writing by his graduate student, a former elementary teacher.

Data Collection and Methods of Analysis

For each workshop, we collected video and audio recordings. One camera was fixed on the entire classroom with a lavalier microphone on the lead instructor. Two additional cameras in each workshop were fixed on small groups, and audio was recorded using a tabletop device. The lesson studied in this paper lasted three hours, so 18 hours of video/audio data were obtained from the two workshops and three cameras. Additionally, each teacher received an engineering notebook they completed. It was intended to help scaffold the activity and to help them with the design and evaluation of the technology. Each teacher signed consent to a protocol approved by IRB.

Our analysis draws on classroom ethnography [34]. In this approach, we view the workshop classroom as a unique culture in which teachers engage in social and cultural practices as they work in small groups. This technique relies on the analysts understanding the normal interactions of the classroom and then zoom in and out to be able to contextualize how and/or why certain interactions occurred. To do this, we first organized the 18 hours of video in to 6 event maps [35], [36]. Event maps are time-stamped records of talk and action of the participants. They are used to consider the amount of time spent in certain interactions, in counting certain occurrences, and for easily finding relevant events for further analysis. The second author used the event map to code for potential instances of teachers engaging in the engineering practices [4] and for phases of the engineering design process described in [37]. Table 2 includes categories and codes used. Each of those codes were cut into clips using Adobe Premier Pro and transcribed word-by-word. The first and second authors discussed each code until reached consensus. In each case, we tried to consider the full range of variation and establish the typicality and atypicality of the events and actions within [38].

Table 2 - Categories and Codes

Category	Code
Scaffolds discourse/activity about engineering	Prompts discussion about problem
	Prompts activity to gain information
	Prompts discussion about possible solutions
	Prompts assessment of solution
Promotes engagement in epistemic practices	Prompts opportunity to reflect on process
	Encourages planning and/or justification
	Prompts comparison of designs/results
	Encourages engagement in some other way

The journals were unnamed but were sorted by the groups using context clues from the video that appeared in the journal (i.e., initial mass of ice cube, cost of design). Content analysis of the text was used [39] to analyze what was written and how it compared among the groups. The journals were also used to compare what they were talking about and doing as they wrote in the journal. We have previously reported on the importance of using both video and journals to better understand what groups were doing and saying – sometimes detail is left out of the journals; other times, observations or decisions deemed unnecessary to speak about are reported in journals [40].

Findings

Using the approach of analyzing both video/audio of the teachers in the workshop and the notebooks they were using provides insight into the ways they used the notebooks in their process to design a penguin habitat. It is important to note, the use of the notebooks in this workshop was not required, so any use was voluntary. Students receiving a grade for notebook completion could potentially have different motives for what and how much they wrote. In this workshop, we found the notebooks were effective at scaffolding discourse and activity of the teachers, and they promoted their engagement in several of the epistemic practices of engineering [4].

Notebooks scaffolded discourse and activities

In this first example, a group of second grade teachers have a discussion after being prompted by the notebook to draw an initial design to protect their ice penguin from melting. In this discussion, the group is collectively talking about what materials they should use and in what ways. In Line 4-7 of this excerpt, Kim shows the group that she wants to use aluminum foil on the top of the enclosure to reflect the heat. She refers to the testing they did on the materials that considered how well they absorbed, reflected, or transmitted heat when telling them to consider the temperature on the foil opposite of the heat source (Table 3).

Table 3 - Second Grade Workshop - Group 1

Time	Line	Speaker	Discourse
00:01-00:19	1 2	Bea	Let's draw it right here. We have a plastic container here. So, you're going to want something on the top?
00:19 -00:28	3	Barrie	Yeah. What temperature do they have to stay at?
00:41 - 00:56	4 5 6	Kim	So you want whatever's on top to reflect the sun away from them, which would be a foil, or ... But then if you're hot, I know you'd like to do we take the temperature on the foil the other side?
00:56 - 00:57	7	Bea	We could
00:57 - 00:59	8	Kim	Cause Penguin will be under it.
00:59 - 01:20	9 10	Barrie	Well, that's a good idea. Oh yeah. they're talking about doing all the backsides.

01:20 - 01:26	11	Kim	Right. We didn't do that. He just did like the front. Right.
01:28 - 01:40	12 13	Bea	Let's get the container to put the material in and we can see how it works
01:40- 01:41	14	Barrie	Would you do the other side?
01:41 - 01:49	15	Bea	Okay. Let's do the wax paper first.

Interestingly, the pictures the teachers drew in their notebook were simple and would not at first glance suggest that significant thought or discussion went into the initial design. All three teachers did the same basic drawing showing they would cover the container, raise the container, and cover 75% of the transparent sides of the container (a constraint on the design set by the instructor) (Figure 2). Despite the appearance of the simple drawing, the notebook initiated an in-depth discussion of their design. However, the teachers did not seem to put much importance on the detail involved in the drawing and instead relied on physical manipulation of the materials and discussion of the design choices rather than on an illustration in the notebook.

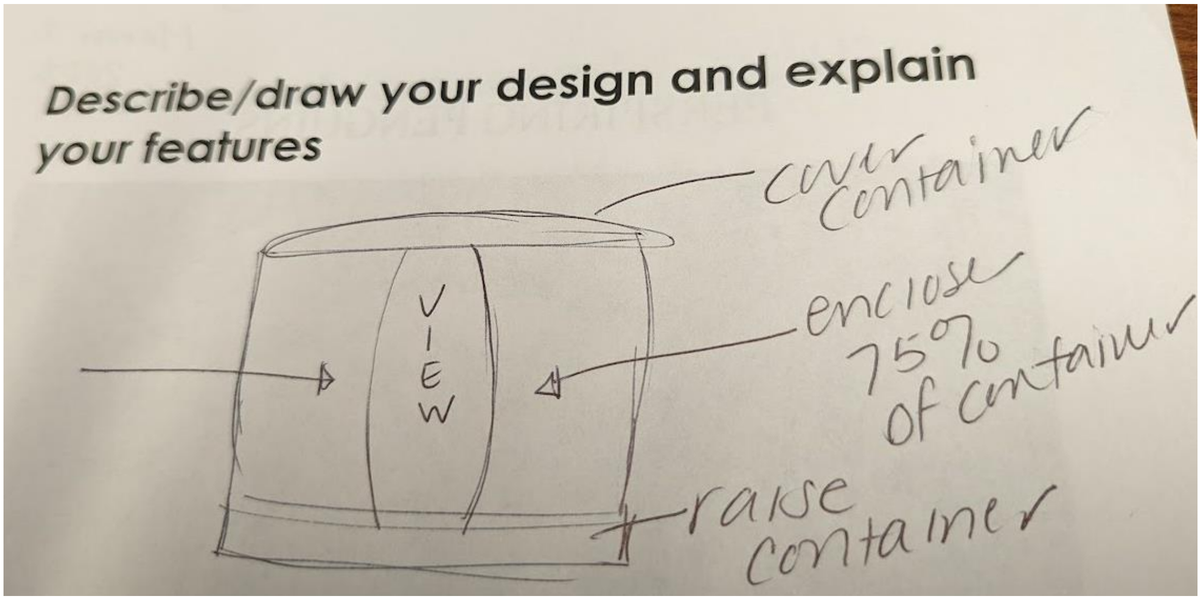

Figure 2- Barrie's notebook drawing shows their initial plan

The notebooks also provided a location for the teachers to collect data themselves that would be relevant to their designs. Teachers were given 45 minutes to test all the available materials. There was no procedure given, but after the group reviewed concepts of heat transfer (conduction, convection, and radiation, absorption, reflection, and transmittance), the teachers were given samples of the materials, a heat lamp, and an infrared thermometer. The page with the materials list served as a cue for the groups to record the results of the tests they ran to compare the materials' properties. While the video data showed that each group had at least one group member recording results of their materials testing, only one wrote in the notebook while most wrote on other sheets of paper. Two examples are shown in Figure 3, and they are used to demonstrate two aspects of how the notebooks scaffold discourse and activity.

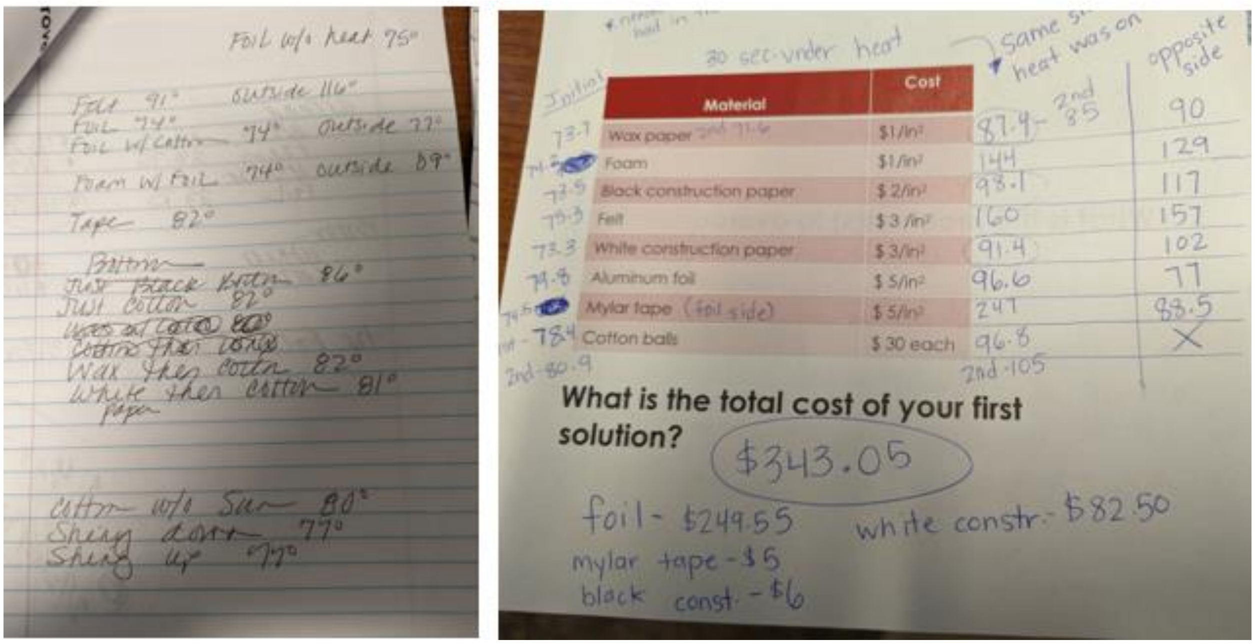

Figure 3 - Teacher-recorded data from materials testing. Hank (left) used a separate sheet while Bea (right) wrote directly in the notebook.

The materials list encouraged the teachers to discuss the relative costs of the materials, to test the ways the materials interact with heat, and to calculate the cost of the design. Despite not providing dedicated space for data collection, Bea's group added to the cost table to record temperatures under different conditions. Hank's group chose to record them on loose-leaf paper. But this ultimately led them to engage in generative discussions to answer questions like, "how do we accurately compare the materials?" and "what is an 'expensive' design?"

Another example of the influence of the engineering notebook on the scaffolding of discourse and activities of the teachers is the way some of the problems can be communicated or emphasized through the prompts embedded in the notebook. One of the most evident challenges in this project is to protect mass loss of the penguin while minimizing the cost. However, the cost of the materials sends a subtle but clear message to the participants – expensive materials can probably be used effectively at reducing melting. Figure 4 is the cost list from the notebook.

Material	Cost
Wax paper	$1/in^2
Foam	$1/in^2
Black construction paper	$ 2/in^2
Felt	$ 3 /in^2
White construction paper	$ 3/in^2
Aluminum foil	$ 5/in^2
Mylar tape	$ 5/in^2
Cotton balls	$ 30 each

Figure 4 - The cost of materials list from the engineering notebook used by teachers

All the teachers in the workshop we observed picked up on this aspect of the challenge. Cotton balls have properties that lend themselves well to insulating the enclosure. And Mylar and aluminum foil both are effective at reflecting radiation, so these materials are the most expensive items available to be used in the design. The second transcript shows how the inclusion of the cost list in the notebook prompts the teachers to discuss this aspect. Daryll, Angie, and Taylor realize they should have used their time investigating properties of the materials differently and investigated the most expensive items first.

Table 4 - Group 2 in the 2nd Grade workshop discusses the cost of materials.

Time	Line	Speaker	Discourse
00:00 – 00:13	1 2	Daryll	Well, whichever one of these is the most expensive, probably what we want to have. But we didn't test the cotton balls
00:14 -00:15	3	Angie	We didn't what?
00:15 - 00:16	4	Daryll	We didn't test the cotton balls
00:18 - 00:25	5	Angie	Let's hear what the others say about that, maybe.
00:25 - 00:27	6	Daryll	We didn't test the film, either
00:27- 00:35	7 8	Angie	The only thing is the cotton balls because there's going to be spaces where the energy gets through, right?
0:35 – 00:36	9	Taylor	They are expensive.
00:36- 00:43	10 11	Daryll	Yeah, I know. That's why I'm like, a little bit like, the maybe maybe I should have checked this out.

In this case, the notebook sends a message to the user that the best way to navigate this activity is to come up with innovative ways of using inexpensive materials or to be creative with the ways in which they maximize the use of small amounts of expensive materials. Because this activity allowed for a second iteration of design and testing, this group went back and were innovative with (at least) two design choices. They used foam (inexpensive) as an insulator, and they used the removeable backing of the mylar tape as a separate material to lift the container off the hot floor of the heat box. They improved in both cost and mass loss percentage.

Based on our analysis of these two workshops, the engineering notebook served as a useful pedagogical tool for the instructors. It was used to support teachers' understanding of the directions, encouraged them to have important discussions about design, evaluation, and strategies for improvement. Many of these activities the teachers engaged in are aligned well with the *practices* of engineering, an important aspect of elementary science and engineering learning according to the *Next Generation Science Standards* (NGSS) [1].

Notebooks encourage engagement in engineering practices

Many of the discourse and activities encouraged by the notebooks can be analyzed through the lens of *epistemic practices of engineering*. While NGSS mostly emphasizes the similarities between engineering and science, Cunningham and Kelly (2017) reviewed the literature to identify sixteen engineering practices useful in the classroom and important in engineering design.

Practice #1 – Applying science knowledge to problem solving

In Table 4, Daryll, Angie, and Taylor recognized that the more expensive materials were likely better at protecting mass loss of their penguin, but they realized it at the end of the time for designing their first prototype. Table 5 is an excerpt from their discussion during their redesign.

Table 5 - Daryll and Angie apply science knowledge to problem solving

Time	Line	Speaker	Discourse
00:02 – 00:17	1 2 3	Daryll	What if we did the Mylar tape, it would be expensive. It's probably not the best solution. Oh, what's aluminum foil, the most expensive?
00:17 -00:25	4	Angie	Same side heat is on. So the heats in
00:25 - 00:37	5 6	Daryll	You would want to look at this if you're insulating it, because it's going to be the opposite side of what the sun's taking.
00:37 - 00:38	7	Angie	So it was the coolest, right?
00:38 - 00:50	8	Daryll	Right. Yeah
00:50- 00:51	9	Angie	Wax paper?
0:51 – 01:00	10 11	Daryll	I think like that's like not good, cause it's only a dollar. Or is is that they're trying to trick us
01:00- 01:07	12 13	Angie	Okay, wait. So when the light's coming in, we need that. The light is coming. Okay.
01:07 – 01:11	14	Daryll	You want the opposite side to be cool inside, right?
01:11 – 01:13	15	Angie	The opposite side to be cool.
01:13 – 01:19	16 17	Daryll	We also want to reflect it. And it will be cool because it's going to reflect the sun back.
01:19 – 01:25	18	Angie	And that's what the…I mean 88.5, 90
01:25 – 01:29	19	Daryll	Or maybe a wax paper wouldn't reflect it.
01:29 – 01:32	20	Angie	This doesn't seem like it would, but…
01:32 – 01:42	21 22 23	Daryll	I worry that this will absorb it, that the sun. I think about my black T-shirts. You know what I mean? Wearing a black T-shirt, it makes you hot
01:42 – 01:45	24	Angie	Yeah, maybe. I don't know.
01:45 – 01:47	25	Daryll	What was the white paper?
01:47 – 01:59	26 27	Angie	White. One of the office that wanted to take four was a cool and the Mylar tape and wax paper.
01:59 – 02:01	28	Daryll	Try it
02:01 – 02:03	29	Angie	It doesn't seem to make sense, butt
02:03 – 02:15	30 31	Daryll	No, but it is cool. On the opposite side, it's not going to be…something will reflect the sun away. I don't think, does it?

In this episode, Daryll and Angie engage in several engineering practices, but this is a good example of applying science knowledge to the design. According to their notebook, their primary strategy for improvement was to utilize materials like foam to insulate the interior of the habitat to prevent melting. In line 12-14 Angie and Daryll articulate that the insulator (foam) would serve as a barrier. Then, in lines 21-23, Daryll compares the black foam insulation to a dark-colored shirt and his experience with the phenomenon of dark clothing absorbing heat.

Another example of notebooks encouraging engagement in *applying science concepts to problem solving* occurred in the workshop for 4th grade teachers. Jared and Willa had the discussion in Table 6 during their design after they tested all the materials.

Table 6 - Jared and Willa apply science knowledge to problem solving

Time	Line	Speaker	Discourse
00:01 – 00:05	1 2	Jared	We're going to need something on the bottom from the heat coming up.
00:06 -00:07	3	Willa	Yeah
00:06 - 00:33	4 5 6	Jared	So ... cotton balls or like.. but they're expensive. But the...That what I think about. We'll layer the bottom so the penguin is on top of that. So the heat doesn't come up.
00:37 - 00:38	7 8	Willa	Could we use…Would wax paper do the same thing? Because the wax paper only changed three degrees.
00:38 - 00:50	9	Jared	Right. Yeah
00:50- 00:51	10	Willa	Wax paper?
0:51 – 01:00	11 12 13 14	Jared	We're worried about not so much, what do we call the... like a pan, the induction like heat coming up through from a touching. I guess if we balled up the wax paper, set it on that like somehow like, this stuff to the top of the bottom.
01:00- 01:07	15	Willa	Yeah

In this example, they compare the use of cotton balls and wax paper. Jared first suggests they use cotton balls (Line 4-6). But Willa suggests they could use wax paper, which would be cheaper and do the same thing, because cotton balls cost $30 each, while the wax paper is $1/in^2. Then, Jared applies his understanding of conduction in his explanation of using either a layer of cotton balls or “balled up” wax paper to prevent contact between the penguin habitat and the hot floor.

Practice #2 – Making evidence-based decisions

During this design project, the teachers engaged in many of the practices of engineering. However, one of the other practices that is clearly influenced by the notebook is the ability to make evidence-based decisions. Table 7 shows a discussion between Barrie and Bea as they are designing their penguin enclosure.

Table 7-Bea and Barrie make evidence-based decisions

Time	Line	Speaker	Discourse
00:01 – 00:05	1	Barrie	Yeah, that then the white construction paper. Hmm. I can’t believe the cotton balls are...
00:06 -00:07	2	Bea	But look how much the cotton balls are (points to notebook).
00:07 - 00:09	3	Barrie	Yeah, that’s expensive.
00:37 - 00:38	4 5	Barrie	I know I still go back to the wax paper because it was only 87.4 and only 90.
00:38 - 00:50	6 7	Bea	Can you have your cotton balls and, like, wax paper around it? I don’t know. I think the wax paper would be strong enough.

Table 7 demonstrates the advantage of being able to analyze both what the teachers are saying and doing as well as what they write in their journal. In lines 4 and 5, Barrie references data from her notebook. Her references to 87.4 and 90 can be seen in her notebook in the upper right corner of Figure 3, their data collection about wax paper. The reference to 87.4 was the temperature of the wax paper after they heated it. The second temperature was referring to the temperature on the other side of the wax paper after heating (a measure of heat transmission). After considering white construction paper, Barrie convinced Bea that they should alter their design to incorporate wax paper because not only is it less expensive, but the data also showed that it was better in absorption and transmission of heat compared to white construction paper.

This practice was also found in Table 6. In a similar discussion to Barrie and Bea, Jared and Willa grapple with the value of cotton balls. They, like all the groups, tried to find alternative materials from their list, and used data from their notebook to justify their decision or persuade their group members that a change should be made. In Lines 7-8 of Table 6, Willa says, "could we use…would wax paper do the same thing? Because the wax paper only changed three degrees." She refers to the data they collected, prompted by the notebook, about the interaction of the materials and heat coming from a heat lamp. Their tests had demonstrated that the wax paper did not increase much in temperature and should be considered as a low-cost alternative to cotton balls.

Conclusion

Our analysis of two elementary teacher workshops about teaching engineering demonstrated the influence of using engineering notebooks to scaffold discourse and activity and to encourage engagement in the epistemic practices of engineering. It was found that although teachers were not required to complete the notebooks, they were used as a tool to help them plan and improve their design, gain information about the materials and processes, and evaluate the performance of their prototypes.

It has been shown in other elementary teacher workshops on engineering that teachers benefit from experiencing engineering as a learner and to have the opportunity to reflect on the process as a teacher [32]. Classroom (and workshop) engineering typically relies on group work and shared discourses and activities. Notebooks can serve as a pedagogical tool by teachers and professional learning facilitators because they support these interactions and activities.

Notebooks thus serve as scaffolds for many supports learners need as they tackle complex engineering designs. This *distributed scaffolding* [41] supports students epistemic practices and ultimately their learning. In this project, the notebook became a member of the group and participated in providing information and directions to teachers as they needed to know what aspect of the problem to address next. It served as a location to communicate design plans, to collect data in materials testing, and to evaluate designs in multiple iterations. In addition, the notebooks became evidence in which teachers suggested design ideas or justified changes to their group members.

The use of notebooks as a pedagogical tool for teacher workshops has been shown here to be a productive pedagogical tool. However, they should not be confused with engineering notebooks that are used in more sophisticated ways by professional engineers [9]. Professional engineers are not given a prepared series of prompts to help them through their process. Instead, they rely on their experience and mentors as to how to use their notebooks to support their work. Teachers rarely have experience in doing engineering, and their students will not either. However, notebooks prepared in this way are effective in supporting teachers and their students in conducting classroom engineering projects and participating in productive discussions and activities as they mimic the practices of engineering as they learn disciplinary content about science and engineering.

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