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Elementary Student Engagement with Digital Engineering Notebook Cards (Fundamental)

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Elementary student engagement with digital engineering notebook cards

Seminal research in elementary mathematics and science education suggests the importance of looking beyond individual students and attending to classroom communities of practice (Chazan & Ball, 1999; Cobb et al., 2000, Gresalfi, 2009; Michaels & O'Connor, 2012; Roseberry, Warren et al., 2010). However, questions about disciplinary classroom microcultures during pre-college engineering education have been addressed by just a small number of research groups (Capobianco, Lehman, Huang, & Nyquist, 2016; Hertel, Cunningham, Kelly, & Lachapelle, 2016; Jordan & McDaniel, 2014).

There is a need for more work in this area because an increasing number of U.S. elementary schools are working to offer their students formal engineering learning experiences (NAE and NRC, 2014). These schools are responding to the public's demands for STEM and STEAM education and to the inclusion of engineering in the *Next Generation Science Standards* (NRC, 2013). Accordingly, a growing number of organizations offer K-5 curriculum materials that include engineering design challenges, such as *Engineering is Elementary (EiE)*, *PictureSTEM*, *FOSS Next Generation Edition*, *LEGOEngineering*, *TeachEngineering*, PBS *Design Squad*, and more. After elementary educators make curricular choices from the range of options, their next decisions are often about scaffolds, technological tools, classroom norms, differentiation strategies, and other instructional supports. They might ask: what instructional supports can we add to engineering curriculum materials to create a learning environment where all students can fully participate in engineering design? What kinds of classroom norms do we need to establish for productive engineering work to take place? These questions may be especially important in schools where students do not frequently have opportunities to engage with their peers in the kind of collaborative decision-making required by engineering design.

To begin to answer these important questions, we are conducting a multi-year design-based research project investigating engineering language and literacy demands, resources, and supports in economically disadvantaged urban U.S. elementary classrooms using the *EiE* curriculum. This work involves identifying more and less productive ways that adults and tools can help elementary students access engineering Discourses and give students agency in creating taken-as-shared disciplinary approaches to design tasks in their classrooms (Wendell, Wright, & Paugh, in press). As part of this research, we are developing and studying an iPad-based digital notebooking tool to support students' collaborative engineering design. In this paper we report on a qualitative case study guided by the research question, *how do elementary students interact with multimedia notebook cards designed to scaffold epistemic practices of collaborative engineering design?*

Framework

Theoretical perspective

Our study is grounded in the view that learning engineering involves becoming a more legitimate participant in a sociocultural practice and that engineering design challenges offer a situated learning context (Lave & Wenger, 1991). Recognizing that language and literacy are central to the sociocultural practice of engineering, we draw upon work in disciplinary literacies (Wilson, Smith, & Householder, 2014) and engineering design thinking (e.g., Crismond & Adams, 2012) to identify the various ways that educators might help their students represent and communicate meaning during engineering learning experiences.

Engineering design is a social practice with disciplinary ways of knowing, doing, talking, reading, and writing – what some might call disciplinary language and literacy practices (Fang, 2012) or disciplinary Discourses (Gee, 1996). As a result, in an elementary classroom, engineering design challenges have the potential to be both "discourse enabling and discourse dependent" (Moje et al., 2001). This means that engineering design can create a different space for elementary students to do sophisticated things with language and to think and interact in intellectually sophisticated ways. At the same time, students may need support to engage in the language and literacy practices upon which engineering depends (Lee et al., 2013). Published research offers some characterization of these language and literacy practices (Atman, Kilgore, & McKenna, 2008; Darling & Dannels, 2003), but it does not make these practices easily accessible to elementary educators, nor does it shed light on how engineering Discourses are productively and unproductively taken up by elementary-age students.

Research informing tool design

The engineering notebook tools that we are developing are informed by existing paper-based science and design notebooks (e.g., Kolodner et al., 2003; Fulwiler, 2011), computer supported collaborative learning environments for science inquiry (e.g., Bielczyc & Ow, 2014), research on classroom support for science notebooks (Hapgood, Magnusson, & Palincsar, 2004), and current frameworks for and conversations about quality K-12 engineering (e.g., Moore et al., 2014). Notebooking tools are one piece of distributed scaffolding, and in science education, they usually work hand-in-hand with classroom structures and practices (Fulwiler, 2011). Ideally, in engineering education, the classroom structures set up around design notebooks help students see them as personally useful for designing and for sharing, as opposed to assignments to be completed only as part of "doing school." Accordingly, we are investigating templates for engineering notebook pages that are not ordered— so students can add whichever kind of page is useful to them at a certain time.

Digital notebooking tool

The engineering notebooking tool used in this study consists of a set of templates for "notebook cards" that, when filled in, comprise teams' digital engineering notebooks. The five most common cards are: "Problem," "Ideas," "Test," "Final Design," and "Feature." Each card type highlights a different element of engineering design discourse. Taken as a whole, the cards are intended to provide explicit access to disciplinary practices and to mediate the construction of a shared language among student designers. The prompts on the cards are simple, but intentionally worded to cue students to engage in different epistemic "games" (Collins & Ferguson, 1993) and discourse. Each card has a designated place for a photo or drawing; photos are easily added through the iPad's camera function, without leaving the notebook. Students add cards as they work; each time they add a card, they can choose the most appropriate template for their work at the moment. As a result, students' notebook cards do not necessarily follow a pre-determined order.

Figure 1. Card templates available to students on iPad tablets during an engineering design task and an example of a student-produced *Test* card.

We view the notebook cards as one piece of distributed scaffolding, along with classroom structures and practices. Ideally the cards are used as part of a sequence that begins with the introduction and discussion of a "mentor text" notebook comprised of cards that document another student's design process and artifacts. Students view and critique these to become familiar with the kinds of representations that the notebook affords and the extent to which the notebook can tell the story of another engineer's ideas and outcomes. After this mentor text discussion, the students embark on a design task and create their notebooks as they work. Mid-design share-outs or gallery walks of the notebooks are important in this phase. Finally, the third phase involves students reviewing their notebooks with their design team, ideally as they prepare a report or other more formal written artifact about their design, and the teacher and whole class of students reviewing multiple notebooks to reflect on design processes and phenomena.

Other supporting classroom practices that we assume to be in place alongside the formal structures noted above include classroom norms around group work and teacher moves for eliciting and responding to student thinking. We envision a particular teacher and student stance towards the notebooks: ideally, students should see them as personally useful for designing and for sharing, as opposed to completing them only as a school assignment. Theories on scaffolding (Wood, Bruner, & Ross, 1976), strategies for "complex instruction" with groupwork (Cohen & Lotan, 2014), and ideas about cognitive apprenticeship (Brown, Collins & Duguid, 1989) and epistemic forms and games (Collins & Ferguson, 1993) guide this part of our work on participation structures to support students in accessing engineering discourse practices.

Research question

In this paper, we report on a qualitative case study guided by the research question, how do elementary students interact with multimedia notebook cards designed to scaffold epistemic practices of collaborative engineering design?

Methods

Participants and context

The first classroom implementation of the notebook cards took place in two culturally and linguistically diverse fifth grade classes with the same teacher in an urban public school in the northeastern U.S. A majority of the students were from families that spoke a language other than English at home; many students or their parents had been born in the Dominican Republic. For the last three years, the teacher had been implementing two to three *Engineering is Elementary* (*EiE*) units per year to supplement her language arts and social studies curriculum.

The unit used in this study was the second *EiE* unit for this academic year, and it was a modified version of the *EiE* Harnessing the Wind: Designing Windmills unit (Engineering is Elementary, 2011). The teacher chose to contextualize the windmill design task with the biographical text *The Boy Who Harnessed the Wind* (Kamkwamba & Mealer, 2015) instead of with the storybook provided by the curriculum. But the unit's design challenge, to construct a miniature windmill capable of lifting a cup of washers when placed in front of a fan, was unchanged.

The notebook cards implementation took place over four class days in June. The teacher grouped the students into teams of three and provided one iPad per team. Below is a synopsis of the four days. Both fifth grade classes met for about one hour on each day (and rotated to another teacher for other subjects).

Day 1: Discussion and demonstration of connections between the biography of William and the design task.

Preview of final writing task ("For an audience of teachers whose students will construct windmills, explain your windmill design by writing about its parts and their interactions; details about materials, properties, and functions; and reasons why you made your design choices.")

Day 2: Materials exploration, notebook introduction with "mentor text," team planning with *Ideas* cards

Day 3: Building, testing, iterating windmills, documenting with notebook cards

Day 4: Oral presentations and writing task, supported by completed notebooks

Data collection and analysis

Our overall project follows a design-based research approach (Cobb et al., 2003). The particular case study reported here took place during pilot-testing of supports based on findings from the baseline phase. At least two members of the research team were participant observers in the classroom each day. Data sources included researchers' field notes, digital notebook artifacts, video recordings of small group and whole class work, and final oral presentations and written design reports.

We used qualitative case study and microethnographic analysis techniques (Bloome et al., 2004; Merriam, 1998) to explore students' trajectories through the design challenge as they interacted with the notebook cards. With the goal of making and supporting claims about the students' response to the notebook card supports, research team members reviewed video excerpts and digital notebook cards, and then proposed claims and supporting evidence. Conclusions emerged when the team confirmed claims with multiple pieces of data and failed to find counterexamples.

Findings

For simplicity, we organize our findings chronologically, looking in turn at the four main phases of the lesson and asking: How did the cards and students interact during planning, building and testing, presenting, and writing?

Planning

On the second day of the lesson, the task was described to the students again, students were given samples of available building materials to explore, a mentor text notebook was reviewed and discussed, and then student teams were asked to fill in *Ideas* cards with their ideas for their windmill designs. Students were required to have a sketch on their card and to clearly indicate the materials they planned to build with; only the specified materials were given to each team on Day 3.

One unexpected benefit of having students draw their ideas at this point was that it revealed to the teacher and researchers how students understood the design task. Because the tower (a milk carton) and hub (styrofoam ball) were pre-assembled for each group, students were only tasked with designing the windmill blades. However, some groups sketched a windmill tower and began discussing materials to use to build it. It was useful for the teacher to be aware of this misconception of the task at this point, before students spent time or materials solving a problem that had already been solved for them.

Some groups discussed different ideas and documented two options on the Ideas card; often the two ideas used different numbers of blades, blade shapes, and/or materials. For example, in the Ideas card shown in Figure 2 below, one idea uses 'raindrop shape' blades and the other 'rectangles'. Likely in part due to the difficulty of drawing on a screen with a finger, the designs were more conceptual and lacked much detail.

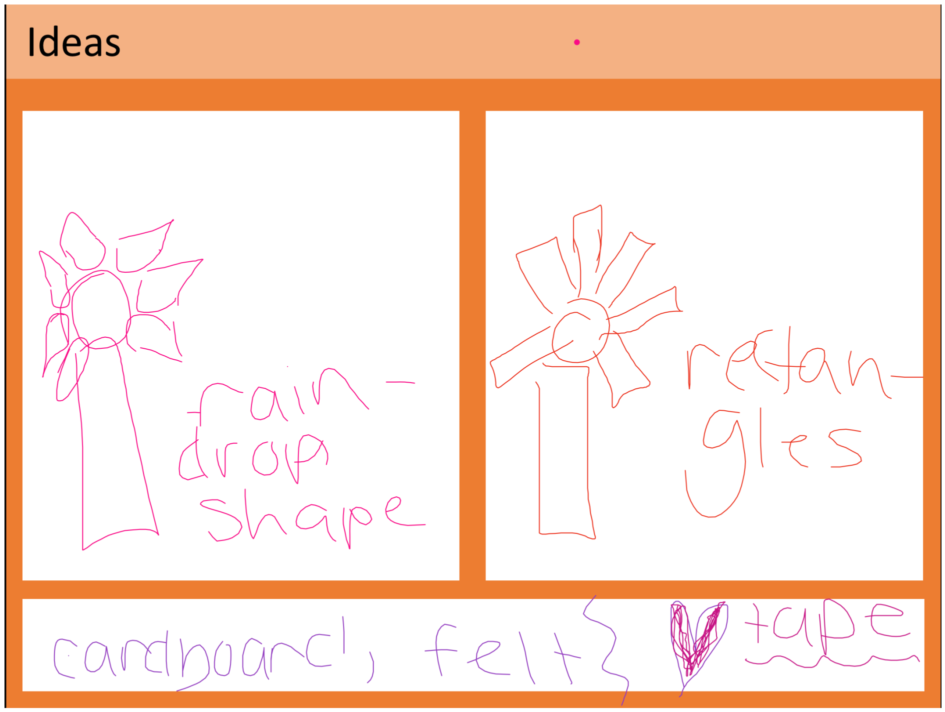

Figure 2. Example of a student group Ideas card for the windmill challenge, showing designs with different shaped blades.

From the data, it is not clear if filling out an Ideas notebook card actually helped students plan their designs more than verbal discussion would have; the digital Ideas card certainly did not on its own seem more productive than drawing on paper. When creating the notebook, we realized that some practices, particularly drawing, may not transfer well to the tablet medium. However, it is always possible for students to draw on paper and then add the drawing to the notebook by taking a picture of it. Although some design practices are not well preserved on the digital notebook, the benefits of having the entire design process documented together in a single notebook, where it is easy to refer back to previous ideas and tests and edit those cards, seems to outweigh the lack of drawing fidelity. Additionally, because it is nearly impossible to create perfect drawings when you are sketching with a finger on a small tablet, the bar for drawing in the notebook is lowered. As a result, it is less likely that only the "artistic"-designated students feel confident enough to draw for their group. Another benefit to having an Ideas card in the notebook is that students can add new Ideas cards at any point in the process, which emphasizes that idea generation does not simply occur once at the beginning of the design process but is constant throughout.

While these data may point to an inadequacy of the notebook and/or classroom structures, it could also be that drawing is not a useful way to plan for this task. As Welch (1999) found in his structures task, students often prefer to plan with physical materials, rather than by sketching. This may be particularly the case in this task, where students, for example, may be unsure without experimentation how many blades can reasonably fit into the styrofoam hub or unsure how securely different materials will attach into the hub.

Building and testing

We found that in this task, students' first time using the notebook, the cards did not seem to support students' independent iterative build-test-redesign cycles as we had hoped. The classroom teacher and supporting researchers frequently prompted students to fill in Test cards as they worked, sometimes asking them to pause before testing to fill in a Test card or following groups back to their tables to ensure they completed the Test card. There is little evidence that students created cards in a self-determined effort to remember the results of a test. Thus, despite intentionally designing the cards to promote student agency, in this first use, the cards quickly became a top-down, teacher mandated task, rather than a student-driven means for documentation of work in progress. As a result, the notebooks seemed more disruptive during the building time than supportive of iteration with reflective decision making. Based on this analysis, we are investigating approaches to incorporate more epistemological discussions at the beginning of the lesson to get students thinking about how and why record keeping may be useful for their designing.

Of course, it is also important to remember that this was the first use of the notebook cards for these students; tentative evidence from in-progress data collection at a different elementary school suggests that over time, students may begin to see the cards as productive for their building and testing and as a result assume more agency over their notebooks.

Presenting

In contrast to the nonessential role that the notebook cards played during planning and building activities, their role during students' final share-outs of their windmill designs was much more central and supportive of students' disciplinary Discourse. On Day 4, the teacher invited two teams in each class to present to all of their classmates on their design constructions and design process. The presenting students stood at the front of the classroom and used their cards (displayed via an LCD projector) as a key visual aid both to organize the structure of their oral presentation and to support the claims they were making to their classmates. The cards appeared to apprentice the students into the language practices of sharing about an engineering design process, and the photos on the cards allowed deeper discussion between the presenting students and the teacher, as they provided more detail than just sketches or notes. We use Emma and Gabriel's presentation as an episode to illustrate these findings.

Because of the compressed schedule for the windmill unit, there was not time for all teams to present. The teacher chose two teams in each class whom she thought would take the task seriously and handle the social pressure of being in front of their peers. (Presentations in front of the full class were not a regular part of classroom activity.) Emma and Gabriel were one of two teams selected to present in the first of the two fifth-grade classes. A third team member had worked with Emma and Gabriel on the windmill, but he was not in the classroom on Day 4. Only a few minutes passed between the time Emma and Gabriel were asked to present and when their presentation began, and the video record indicates that they did not rehearse or even discuss what they would say. During their presentation, Gabriel held the iPad and controlled which cards were shown, while Emma held and demonstrated with the design artifact. The large screen projection behind Gabriel and Emma mirrored their iPad. The team's three test cards, shown during their presentation, are provided below (Figure 3). There were three iterations of their windmill design: first, a design with three rectangular foam board blades angled about 20 degrees from the plane of rotation; second, a design with four foam blades in line with the plane of rotation; and third, the four foam blades again angled about 20 degrees from the plane of rotation.

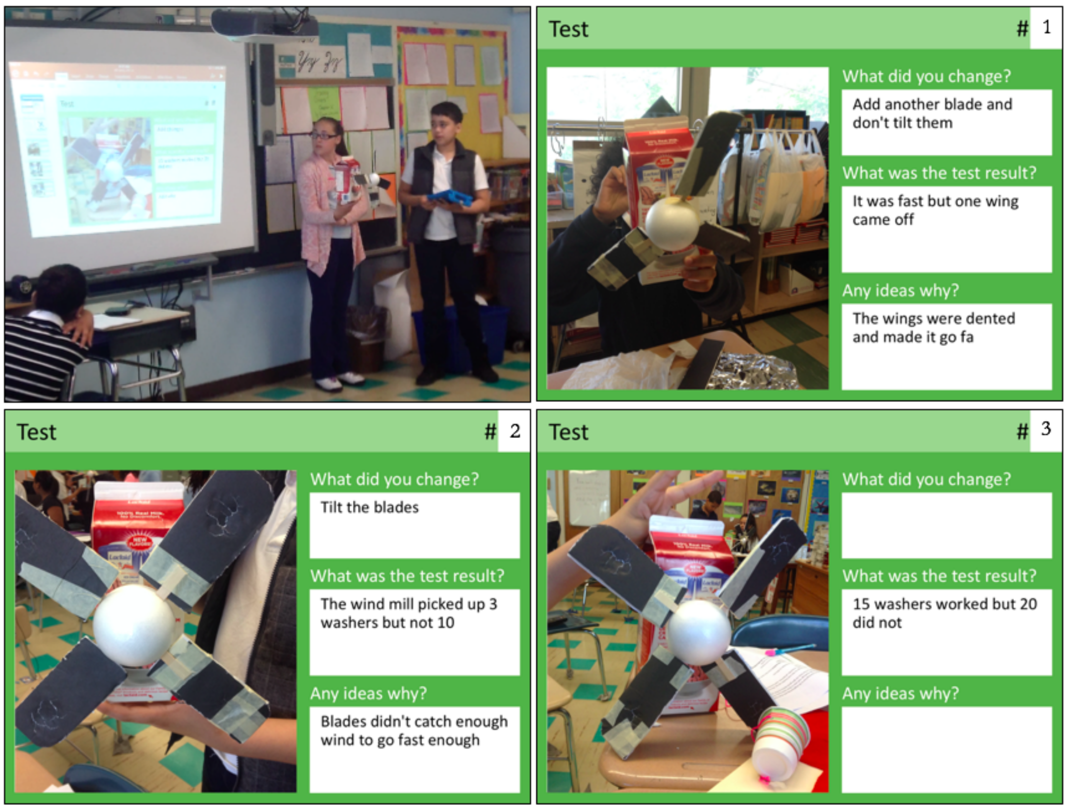

Figure 3. Emma and Gabriel and the three Test cards they presented in front of their classmates. *Note:* In the Test cards, the prompt, "What did you change?" was intended to record what students changed before that test, but this group, like a few others, answered the prompt with what they planned to change after the test. Thus, the change written on the first card ("Add another blade…") is seen in the picture on the second card.

Gabriel began the presentation (Line 1, below) by showing their Problem card and Ideas card in sequence while stating that their overall intent was to make the blades "diagonal" so that they "could catch the wind." Having these two cards appear at the beginning of the notebook seemed to give Gabriel time to make this general statement about his team's orientation toward solving the windmill problem. He did not read verbatim off the cards, which was appropriate because everyone in the audience knew about the design problem and didn't need Gabriel to re-hash the criteria and constraints. Gabriel then proceeded to give a well-organized narrative of their three tests. As he advanced the iPad to each next Test card, his pattern was to state generally whether that iteration of their windmill design "worked," give a possible reason for that iteration's performance, and describe the change they made as a result. Although the structure of Gabriel's oral language may not appear to be that complex, it is notable for its coordination of the language demands of procedural recount ("When we," "so we") with those of explanation ("because"). Here are his opening remarks:

1 Gabriel: [Problem card projected on board] When we were building the windmill blades, we were trying to make it - the blades - we were trying to make them diagonal, so then the wind could catch--I mean and then the blades could catch the wind.
[Ideas card shown] And then we have the idea right here [gestures to slide]. When we did our first test, [Test card 1 shown] it worked, but it didn't go that well because one of the blades fell off when we were testing it, so we tried a different idea [Test card 2 shown] of making it four and making it three [unclear, possibly referring to lifting 3 washers]. Um it worked but the wind wasn't catching -- the fan wasn't catching enough wind. [Test card 3 shown] So then we did this. It got a lot of wind and it got -

At this point in Gabriel's presentation, the classroom teacher interjected (Line 2, below) to ask Gabriel to clarify what he meant when he said "So then we did this," while showing their last Test card. Because that Test card included a photo of their last iteration, it supported Gabriel and Emma in answering that clarifying question (Line 3). The cards also made it easier for one of the researchers to refer to the students' oral report about their test results and ask them what made the two iterations different (Line 6). When Gabriel gave a response that seemed to conflict with their Test card photos, the researcher could press for accuracy (Line 11). Rather than having to try to remember which number of blades they were using in which iteration, Gabriel used the Test cards as a resource. He flipped back through all three Test cards and found the key factor that differed between their less successful and more successful tests: the angle of the blades, not the number of them (Line 13).

2 Teacher What did you do here--you said, "then we did this." What did you do in the next step?

3 Gabriel: When we did this, we made the--we still had the same idea with four but this time we had it diagonal. And then it caught a lot of wind. It went up to twenty washers? [looking at Emma]

4 Emma: Fifteen.

5 Gabriel: Fifteen.

[Pause in presentation, teacher explains task to a classroom visitor]

6 Researcher: Can you tell me one more time what happened between the test where you picked up three washers and the test where you picked up fifteen? What did you change?

7 Gabriel: [Test card 1 shown] We changed it to have four because when it had three it didn't catch enough wind.

8 Researcher: Okay.

9 Emma: No we had four [blades] when it picked up three [washers].

10 Gabriel: No [looking at iPad].

11 Researcher: It looked like there were four on both pictures.

12 Teacher: Yeah, I thought so too.

13 Gabriel: [Flips through cards] Oh yeah because this one [Test card 2 shown] was straight but this one [Test card 3] wasn't.

14 Researcher: Straight and then not straight.

15 Teacher: So you changed the angle of the blades?

16 Gabriel: Yeah, yeah.

The notebook cards enriched Gabriel and Emma's presentation in three ways. First, they helped Gabriel organize his initial recount of their design process and coordinate that with an explanation of the design changes they made and the test results they observed. Second, they gave irrefutable information about the state of the design artifact at each test, so the adults in the room could press for details and help the students report accurately to their classmates and attend to important physical factors (e.g., the angle of the blades in addition to the number of blades). Third, the cards kept the students from getting "stuck" or making up information when asked a question about earlier iterations of their design; they could simply swipe back to the photo they had taken and the corresponding notes they had written about what they changed and what the test result was.

Gabriel and Emma presented a design process and construction that were arguably successful: they iterated twice on their initial windmill design for a total of three different tested designs, and with each iteration their windmill performed better by lifting more washers. Because they represent a "successful" student team, it's reasonable to ask whether the notebook cards offered any support to teams that did not experience success with their design construction during the time allotted for the unit. Next, we turn to the interactions between the notebook cards and a pair of students whose windmill was never able to lift washers. We focus on data collected during their work on the final writing task of the unit.

Writing

Our findings about the interactions between students and notebooks during the writing phase of the unit emerged from analysis of data generated by students Camila and Isabella. Before describing the findings, we first give a brief overview of Camila and Isabella's case. Figure 4 shows their final windmill design. During building and testing, they labored with their third teammate to make three large foam-board windmill blades intricately covered with aluminum foil. Because they spent much time fabricating these blades, they went to the testing station later than most teams, and once there, they hesitated to test because their windmill's hub (a styrofoam ball) kept falling off its axle. When they finally did test their foil-covered blades, they found that they did not spin at all. Isabella wrote on their single Test card, "The hub is too lose [loose]!!!!!!!" Back at their desks with just a few minutes before the end of class, Camila hastily tried a new design that used only wooden craft sticks for blades. She struggled to get craft sticks to remain tightly inserted into the styrofoam hub and ran out of time to test another iteration. Their notebook consisted of just a Problem card, Ideas card, and one Test card (Figure 4).

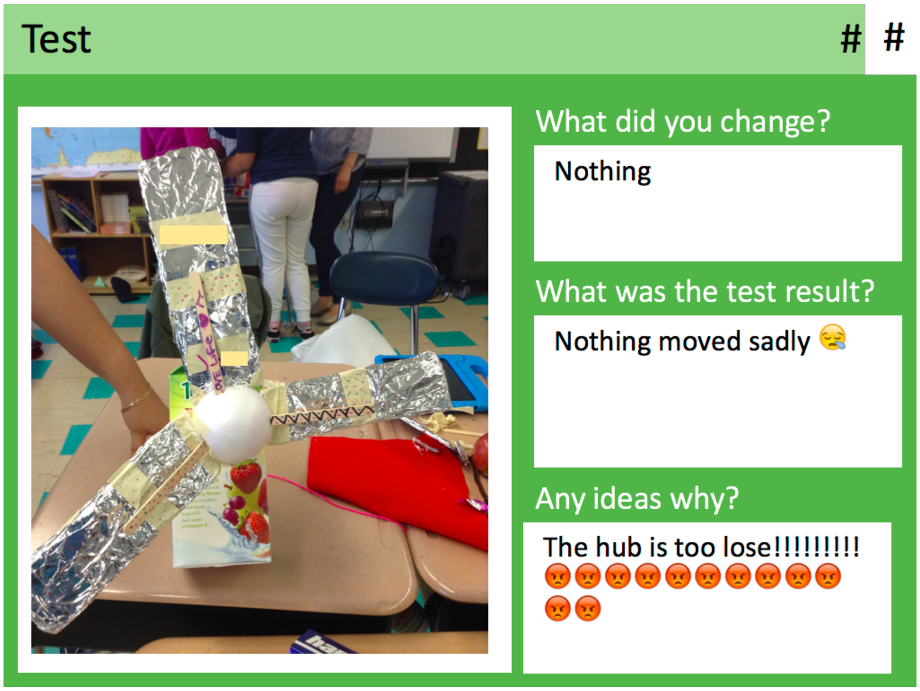

Figure 4. The only *Test* card in Camila and Isabella's notebook, created on the building day and referenced numerous times during the writing task on day 4.

At the end of Day 4, all students worked to write formal design reports that both described their final windmill designs and explained their reasoning behind their design choices. The students were told that their audience was a group of new engineering teachers who would be doing the windmill design unit with their own students: those teachers would read the reports to get ideas about how to help their own students with the windmill design challenge. This writing task had been introduced on Day 1 of the unit, and students had been told that they would have their notebook cards and their final design constructions available to help them in the writing. Their teacher also hoped that the oral presentations in the first part of the Day 4 session would help prepare students for writing. Earlier in the academic year, the students had participated in a writing unit on how to explain how technological artifacts work. In this earlier unit, guided writing and independent practice focused on identifying components of a technology and describing their materials, properties, and functions.

We observed the students while they wrote their design reports and noticed that they typically had their notebooks in front of them, open to their last Test card or Final Design card. One pair of students in particular, Camila and Isabella, frequently gestured toward their iPad as they leaned over their design reports and added sentences. Their iPad displayed their Test card. They adopted a co-writing approach to the report task, with Camila dictating a sentence, Isabella suggesting a tweak or questioning its accuracy, and then both students writing down the same thing. Because their dynamic involved Camila making an initial bid for each sentence with Isabella "checking" it, their glances and gestures at the Test card appeared to preemptively mediate any possible disputes. In the excerpt below, Camila refers to the the Test card both before the researcher approaches the pair and while she is there (Lines 3 and 12 below).

1	Camila:	[After writing about the blades as one part of their windmill] What else?
2	Teacher:	Nothing else, we're done.
3	Camila:	No, and the popsicle sticks. [Begins to dictate a new sentence for their reports] "We putted some," oops, you spelled popsicle wrong [pointing to Test card].
4	Isabella	Yeah. [The girls discuss how to spell popsicle.]
5	Camila:	[Dictating the rest of the sentence] "Wooden sticks in front of the blades to make it more sturdy."
6	Isabella:	[Dictating how she would like to end the sentence] "More stronger."
7	Researcher:	[K comes and sits next to them; they give her the iPad and ask if they spelled popsicle correctly.] How are you guys doing? Are you writing about the parts?
8	Camila:	Good.
9	Researcher:	And how they work together?
10	Camila:	Yeah.
11	Researcher:	Okay.
12	Camila:	[Turning back to Isabella and pointing to their iPad again] We also put some popsicle sticks like inside the foam board to connect it to the hub.

What makes Camila and Isabella's productive use of the notebook cards during writing so compelling is its contrast to their use of the cards during the previous class session. They did not seem to find the cards engaging during building and testing, and furthermore, they expressed great frustration during building and testing. In fact, the video record of the last five minutes of the building and testing session shows Camila and Isabella angrily dismantling their intricately fabricated windmill blades and then Camila desperately trying to get a new batch of wooden craft sticks to stay in the windmill hub. They would not stay because so many holes had already been poked in the styrofoam hub. She throws her hands up in frustration, "I quit! We have to be neater next time, Isabella!" Meanwhile, Isabella quickly fills out their Test card at the last minute, suggesting it has not influenced their design thinking at all.

In stark contrast to these dynamics for Camila and Isabella during the building and testing on Day 3, on Day 4, they seriously engaged with the writing task, chose on their own accord to refer frequently to their digital notebook record, expressed minimum frustration, and developed a clear and complete report. They were able to participate in a positive writing conference with the researcher mediated by both their report and their digital notebook. In this conference, the researcher had opportunities to talk with them not only about their written language but also about the technical details of their test results and their ideas for design improvements. In this way, the cards and corresponding writing task enabled a team that had felt completely unsuccessful at the end of prototype testing to experience substantial success by the conclusion of the engineering design unit. In the appendix we include the transcript from that conference with the researcher.

Discussion and conclusion

The results from this case study were mixed. They suggest that in students' initial sessions with the cards, they may function as more of an intrusion than a support, especially during building and testing if there is not already a classroom microculture that values taking time for documentation and reflection. However, at other times in the unit -- specifically during final oral share-outs and a final writing task -- the notebook cards mediated productive interactions which in turn supported students' engineering design practices and disciplinary Discourse.

During planning and building and testing, the barriers to productive use of the cards seemed to be more due to classroom practices and participation structures than with the notebooks themselves. Specifically, because the adults required the students to create Ideas cards during planning, and frequently urged them to create Test cards during building and testing, students did not actually have agency to take up the cards in a way that was meaningful to them. Of course, the urging was intentional, as the teacher and researchers (based on both previous classroom experience and the design education research literature) suspected that students would not choose on their own to pause, reflect, and document in the middle of a design process. It is still possible that being so didactic about card use in the first iteration increased the likelihood that students will use notebooking on their own in later design tasks. However, there may be better ways to nudge students to use discourse supports in personally meaningful ways.

During the presentation and writing phases, the digital notebooks did seem productive for student thinking and work, and for some students they may have increased their awareness of disciplinary discourses of engineering design. Creating, sharing, and reviewing the notebooks seemed to cue students to engage in particular kinds of talking and writing which were consistent with oral and written genres in engineering practice. When asked to show their notebook cards on the LCD projector and describe them to the whole class, one student team spontaneously organized their oral presentation (which they did not practice ahead of time) by their design iterations, using unprompted language such as, "Then we… because on the last test we found out…." The cards highlighted for them the iterative nature of design. As they presented, these students recounted test results as justifications for the series of design changes that they described. The notebook cards also appeared to deepen students' awareness of the iterative nature of engineering design, as in the case of Camila and Isabella, who ended the unit successfully by making sense of and writing clearly about an unsuccessful yet informative iteration.

This case study is a starting point in articulating and describing the kinds of supports, both tools and teacher moves, that can help elementary students take up disciplinary Discourses productively. This work builds on previous research that characterized language and literacy practices in engineering by providing a concrete example of how these practices can be addressed at the elementary level. Intentional support helped students use their resources to effectively engage in engineering design and to deepen their awareness of engineering Discourse; it also made students' resources visible to their teacher. The findings of this case study can help other researchers and practitioners anticipate how students will respond to digital design notebooking tools and envision supportive teacher moves. The notebooks function as one piece of distributed scaffolding; in particular, we speculate that the notebooks will be more productive when students are given ample time for reflection, which the notebooks can help support. This study's findings can also inspire new digital tools—and related pedagogies and lesson structures—that support other aspects of design practices and discourse. For our project, next steps include investigating how students respond to using an iOS app version of the notebook (now in beta development) multiple times throughout the year on various design tasks.

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Appendix

Transcript from the writing conference between researcher and Camila and Isabella at the end of Day 4

1. Researcher: Can I -- Can we read it?
2. Camila: Yeah
3. Researcher: This is amazing. Alright. (reading) Well the main parts of our windmill is the hub, blades, axle, base, rod. Our blades are made of foam board, and we wrapped some foil around it to make it secure. That's really good like explaining why you did it within that sentence. We put some popsicle sticks in front of the blades to make it more sturdy. That's really great how you explain why you did things. We also put some popsicle sticks inside the foam board to connect it to the hub. We wrapped the foil around the foam board to make it stronger. Since the foam board is weak, it would help it move. Also we put some popsicle sticks inside the foam board to connect it to the hub and make it move strongly. What do you mean by move strongly? So you put the popsicle sticks inside
4. Camila: Like like if it (pause) like if it will be weak, like it will like it will like actually like fall out.
5. Researcher: Mmmm.
6. Camila: And if it will moves strongly it will be like keep going and like straight. (gesturing too)
7. Researcher: So move strongly like keep its structure like
8. Camila: Mhmm
9. Researcher: Like keep the same
10. Isabella: Keep it straight.
11. Researcher: Keep the same shape while it moves. Neat.
12. Researcher: (reading) Our design didn't move at all because the hub was really loose with all the holes around it. You know what I love? I love how you describe the whole design so like I can picture it in my mind, and then you started talking about what happened when you tested it. So even though you're going to tell me now like, yeah, now you're going to tell me why it didn't work and I can go back and think about what it looked like and try to understand. Alright. With all the holes around it, and it fell off the axle because the hole was too big. (reading) I'm thinking (pause) Oh and now you're going to tell me what you would do to change it? (reading) I'm thinking to put 10. 10?
13. Camila: Mhm.
14. Researcher: Ten long blades and make it out of foam board and put some popsicle sticks in it to connect it to the hub, but this time I'm going to make it lighter and-
15. Camila: Neater
16. Researcher: Neater without so my holes poked in the hub. What is that?
17. Camila: So many--Oh! (Isbella joins the table)
18. Researcher: Oh without so many okay so maybe change that. Without so many holes poked in the hub. This is the main reason why our windmill didn't move or function at all. Really nice use of function there. Great. Why would you make it lighter?
19. Camila: Because if I make it heavy, it might like fall forward. (gestures falling forward)
20. Researcher: That is something
21. Camila: And the hub might like keep falling off.