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Understanding Students' Perceptions On The Utility Of Engineering Notebooks

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ABSTRACT

Engineering notebooks are a pervasive practice across high school, college, and professional contexts. Within this consistency, there are two basic forms: process-based notebooks serve as a complete record of the engineer's work and are used by the authors to support their endeavors, while product-based notebooks represent a record of final form projects to be evaluated by outsiders. Given this breadth of purposes, expected content and primary audiences, this paper explores students' and teacher's use and perceptions of the utility of engineering notebooks. In this study, we interviewed students and teachers, and examined the student notebooks, from three different high-school engineering classes. Grounded-theory analyses of this data reveals that all classes used process-based notebooks and they all struggled with supporting student reflection, a common teacher goal. In addition, in each class, the notebooks emphasized a different phase of the design process and students similarly reported the utility of notebooks for supporting that phase. The key instructional implication of this work is that facilitating students' meaningful and thorough use of their notebooks requires creating situations in which maintaining notebooks helps them complete their project work. The paper provides examples, pulled from the study data, of how to enact this strategy.

Keywords: engineering notebooks, grounded theory, high school

INTRODUCTION

Engineering notebooks—also called portfolios or journals—are pervasive in college and high-school engineering courses [2,7,8,9,11,13,14,23,24,27]. In addition, they are a key component of the

BEST robotics competition [4] and the "Engineering Criteria 2000" standards created by ABET for accrediting engineering programs recognize portfolios as a possible assessment tool [25]. The engineering education community therefore appears to have embraced engineering notebooks (ENBs). This paper is a preliminary exploration into high school teachers' and students' perceptions of the utility of their ENBs.

Types of engineering notebooks

A brief review of the literature reveals that ENBs can take many forms and be used for many purposes in the classroom. For example, Tillema and Smith [32] identified three distinct types:

1. A dossier is a ENB or portfolio that is completed at the end of a project or course to "collect mandated documentation on performance. In this case, the portfolio construction is not necessarily based on a learning orientation" [32, p. 194].
2. A learning portfolio is a living document used to evaluate learning over the course of the project or semester.
3. A reflective portfolio is also a living document, in which the author records his or her process, decision-making and reflection.

Shackleford [30] presented a similar scheme that also included a "composite portfolio" which is used to record a group's work. The schemata presented by Tillema and Smith and that proposed by Schackleford both differentiate between ENBs that are used to evaluate student's products (e.g. dossier and learning portfolios) and those that are an opportunity for student or group reflection (e.g. reflective and composite portfolios). Jensen and Harris[32] offer a simpler taxonomy with two types of ENBs, "representational" and "developmental portfolios". Similarly, Christy and Lima [11] differentiate between ENBs that record select samples of student work in their final form ("selective/final") from those that record works-in-progress ("nonselective/working"). These last two taxonomies highlight whether ENBs record *products* or record *processes*. In this paper, we discuss ENBs in terms of the product versus process distinction.

While depicted above as being a distinction that is explored in research regarding engineering education, the product-based ENB and process-based ENB are similarly apparent in the professional practice of engineering. That is, in professional engineering situations, notebooks are used both as living documents for the engineers' reference (recorded and used in the *process* of a project) and as static documents for the company's use (reflecting the *product* of a project). For example, McAlpine [26] shows that engineers refer the ENBs frequently, especially the most recent editions, thereby using them with a process-based orientation. On the other hand, Horenstein [19] describes organizational archiving of ENBs for the benefit of the company at large. For example, the notebooks can be used as evidence admitted to court in arguments regarding intellectual property. In this way the notebooks are product-based documents, where the final product is more useful in its completion than its creation.

Since there are multiple possible purposes, forms, and outcomes of ENBs, we expect that engineering teachers and students may have different perceptions of their ENBs, beliefs about what content should be included therein, and expectations about their utility. Work in science education has demonstrated that student perception of their classroom practices influences whether and how they engage in those practices [3,15,18,22,32,33]. Moreover, Berland and Berland [4], reveal that the stronger the student's belief that the ENBs helped their project work the more they reported maintaining a thorough ENB. This association suggests that student perception of the utility of their ENBs may impact their use of those ENBs and therefore motivates a more careful examination of student and teacher perceptions and uses of ENBs. With this in mind, the current paper explores the breadth of ways in which students and teachers use and perceive ENBs as useful. In particular, we explore the question: how do students and teachers use the ENBs and which aspects are perceived as being most useful by the teacher and student users? We begin by providing a more detailed discussion regarding product- and process-based ENBs, and the methods we used to explore student and teacher perceptions of their ENBs.

Distinctions between product- and process-based engineering notebooks

Product- and process-based ENBs are both used to encourage students to document, reflect upon, and receive feedback about their work in their engineering courses. However, there are two key differences between product- and process-based ENBs: perceived audience and when reflection and feedback occurs. When completing product-based ENBs, students select and record their products upon completion of a project or course. While the selection and feedback process can foster student reflection, these ENBs are typically seen as portfolios that can demonstrate student competency. Thus, external evaluators become the primary audience of product-based ENBs. In contrast, process-based ENBs are for recording, reflecting upon, and receiving feedback on works-in-progress. Creators of process-based ENBs are meant to include preliminary ideas, personally relevant questions, and justifications of decisions made. Consequently, while an instructor might also evaluate process-based ENBs, the primary audience is the author: the ENB is a resource to support the author's progress on his or her design work. We provide examples of both ENB types below and offer a brief discussion of the ways in which they each support student learning.

Product-based ENBs (otherwise known as portfolios) are used to record final form projects. McKenna, Colgate, Carr and Olson exemplify this notebook form in their undergraduate engineering design program in which the final product of the students' work is a design "portfolio." Students "produce an inventory of their skills, select work products that illustrate mastery of their skills, with an emphasis on technical competency [27, p. 673]." Knott et al. [23] provided their students with a more open-ended portfolio assignment and found that the students similarly emphasized this product-based ENB. In particular, the authors found that 69% of the students used their ePortfolio to store final project products and resumes. The remaining 31% of the students included supplementary products such as links to student created websites or computer programs and papers from other courses.

Turns, Cuddihy, and Guan [33] similarly used a web-based portfolio tool in a mechanical engineering course. In this case, students were required to include a "statement about how the course had contributed to his or her preparedness to function as an engineer, a collection of three (or more) artifacts from the course that supported the claims made in his or her statement, and a written annotation for each artifact that explained how the artifact supported one of the claims." The researchers found that the portfolio assignment helped students reflect on their project work. Across studies such as these, we see that product-based engineering notebooks, tend to be used primarily for student evaluation. In addition, they are seen to support student learning by offering students an opportunity to identify their best work; reflect on their process after the fact; and to receive detailed feedback on that work.

Process-based ENBs are much more varied across instantiations and current research does not provide clear descriptions of intended ENB contents. For example, Anderson-Rowland, Reyes and McCartney offer a vague specification of contents of a process-based ENB stating that they included "participant documentation of the process they used to arrive at their final design" [2, p. 4]. Another example comes from Lackey et al.'s [24] work in which students are asked to include two columns in their ENBs, with class notes on one side and reflections or questions on the other.

Even with the lack of clarity regarding content of process-based notebooks, they are emphasized in high school curricula [21], and it is argued that they support learning. Eris [14] exemplifies much of the thinking in this area, arguing that process-based ENBs support learning by: making student thinking public; being open-ended; and enabling students to work on both problems with right answers (e.g., technical problem sets) and ill-structured problems without answers (e.g., conceptualizing novel solutions) in the same physical location. As he states:

> It is very plausible that after engaging in these different inquiry processes (convergent and divergent problem solving) for a period of time within the same environment, students would naturally be able to see connections and bridge them, or at least, would be more open to responding to pedagogical interventions that are aimed to relate them [14, p. 556].

However, there are few studies in the realm of engineering education empirically examining the connection between learning and process-based ENBs.

That said, much has been published related to science notebooks, which are generally analogous to a process-based ENB. For example, Wiebe and colleagues [35], state that although there are many variations of science notebooks, "they share the same goal of scaffolding a written/drawn record of the students' ongoing, reflective experience conducting science activities in the classroom." In their discussion of how teachers may facilitate science notebook use, Fulton and Campbell [18] suggest requiring end products, such as a paper or presentation, that students may create based on what they recorded in their notebooks. In this way, Fulton and Campbell are motivating the students' use of the science notebooks as being a living record of their work that are methodically updated and used in a manner consistent with the way scientists use them.

These process-based science notebooks are shown to enrich "student thinking and meaning making [22, p. 5]." In a study of how students in an advanced high school physics course used their "learning logs," Audet, Hickerman and Dobrynina [3] found that the journals supported conversations between the students, their instructor and the researchers. Similarly, in an examination of a high school genetics course, Finkel [15] related student success to their knowledge of the content, the model revision processes, and their own problem solving process. Finkel's work suggests that the students' notebook supported the students' learning by making their problem solving processes explicit and visible.

The positive connection between process-based ENBs and learning are not restricted to science concepts. For example, in a study of elementary age English Language Learners Amaral, Garison, and Klentchsy [1] found that science notebooks were used with a dual purpose: "to develop cognitive knowledge of science content and processing skills and to enhance [the students'] English writing skills." The researchers found that summative assessment achievement in both of these areas increased in relation to the length of time with which the students were involved in the project. Additionally, Jensen and Harris [20] demonstrated that students in a college communication class believed that notebooks—that included information such as daily journal entries, preliminary speech ideas, peer feedback, outlines of speeches, etc.—supported their learning by helping them identify key concepts in class and relate the course material to daily life.

METHODS

In order to explore the breadth of ways in which students and teachers use and perceive ENBs, we followed grounded theory methods [10]. For this analysis, we worked with three high-school classes, conducting student and teacher interviews, classroom observations, and gathering the students' ENBs, in order to develop thick descriptions of the ways in which they used ENBs and their perceptions of the utility of those artifacts. In this section we describe the data sources and then the analysis process we used to explore student and teacher perceptions and use of the ENBs.

Data sources

Students in each class were expected to maintain an ENB. Each class was taught by a different teacher, in 2 different schools, and was working through different engineering curricula. We expected this variety to result in a variety of perceptions of the ENBs, thereby enabling us to identify a range of possible perceptions and uses.

All three teachers came to engineering education from science backgrounds and were participants in, or graduates of, the UTeach*Engineering* education master's program for current teachers. During this study, all three teachers were working in local high schools that volunteered to include engineering courses in their course offerings.

Collected data for this study include student and teacher interviews, classroom observations and student ENBs. The classroom observations were used to provide an overall sense of each classroom environment. For each class, we interviewed and examined the ENBs of 4 students and interviewed the teacher. Student and teacher interviews were designed to elicit the participant's perception of the value and utility of the ENBs. Interpretations of the content of each student's ENB were used to determine whether stated perceptions aligned with their actual use of the ENB. Taken together, the interviews and ENBs provided different lenses into the how ENBs were used and perceived in each of the participating classes.

The ENBs were either downloaded (in the case of Mr. O's class) or photographed (in the case of Ms. M and Mr. S's classes). The interviews were conducted by the second- and third-authors of this paper. They were semi-structured such that the interviewers had a basic protocol to follow (see Figure 1), from which they deviated to encourage participant reflection. All interviews were video recorded. Students had access to their own ENBs and teachers had access to excerpts of selected student ENBs during the interviews.

Data analysis

Using grounded theory methods [10] to analyze these three data sources (student interviews, teacher interviews and ENBs), we focused on finding patterns within a student's responses to the questions and their work with the ENBs, and across students and teachers in a particular class. We started by examining each individual student's interview responses—looking across their answers to the questions in order to identify the themes individual students emphasized regarding the purpose and utility of their ENBs. We then compared those themes to the individual's ENB. For example, if a student reported using the ENBs to record design ideas, we looked in that student's ENB to see

Student Interview Protocol	Teacher Interview Protocol

1. What is your engineering journal for?
 	
2. Who is this journal for? Who will look at it?
 	
3. What do you put in your journal?
    a. Is your journal useful? Why?
 	
4. Choose a page from their journal which references the "black box" lesson day. Ask what it means—to explain their picture. Ask why they wrote or drew what they see.
 	
5. Do you ever look at your journal to remember what you did previously? Or to help you figure something out?
 	
6. When do you look back and read over or review something in your journal?
    a. About how often does that happen?
 	
7. Did you reference that Black Box diagram after that day? When? Why? (Ms. M's class only)
 	
8. Can you flip through the journal and point out any pages that you've referenced after you made them?
    a. For each page: Why did you reference it? What did you use it for? How soon did you look at it after you made it? (If they reference a lot of pages, stop them after they've discussed 3.)
	1. Why do you have the students doing journals?
	
	2. What do you hope they will get out of keeping these journals?
	
	3. What kinds of things do you hope they will keep in their journals?
	
	4. What do their journals look like (paper, electronic, grid, format, etc.)?
	    a. Why did you choose the media you chose (paper/electronic)?
	
	5. What formatting, organizational guidelines did you give them for how to fill out their ENBs?
	
	6. How did you tell students about these guidelines?
	
	7. Describe the successes and challenges you've had with students following the guidelines.
	    a. Is there anything you would change about the guidelines or how you supported them?
	
	8. How did you support students in keeping their journal up to date?
	    a. Is there anything you would change about this support?
	
	9. Do you believe, at this time, that the journals were valuable to the students?
	    a. Why/why not?
	    b. If no, what would you change to make it more valuable?
	
	10. In the future of this class, do you intend to make any changes regarding their journal use, support, etc.? Why?
	
	11. If graded, what were your grading criteria?
	
	12. Show the teacher an excerpt or two, and ask them what they see.

Figure 1. Student and Teacher Interview Protocols.

if they, in fact, did so. Through this, we were able to characterize each individual's reported perceptions and their use of their ENBs.

After the individual analyses, we engaged in a constant-comparative analysis [12] of the individual classes. That is, we compared across individuals within a class to determine whether the themes that emerged within individual responses were shared across the students in the course. In addition, we compared those emergent themes to the teacher's interview to determine whether the teacher's perception of the ENB's utility and purpose was consistent with that of the students. This final check helped clarify and validate the themes that emerged in the student's work. Throughout this process, we returned to and refine our initial interpretations of the student's perceptions and uses of their ENBs.

As a final analytical step, we compared across the three classes to determine whether the themes that emerged in one class were apparent in the others. This check served as an alternative-hypothesis testing in that a purpose that emerged in one class became an alternative-hypothesis for the other classes: could we interpret student and teacher interview responses in terms of this other purpose? Where necessary, we refined our analyses of the individual student- and teacher- interviews, in light of this comparison. At the conclusion of this pattern-finding process, we had stable interpretations of the student and teacher perceptions of the utility of and purpose for the ENBs in each of the participating classes.

RESULTS

Our analysis is organized around each individual class. We begin by providing overview information regarding the teacher and the way he or she supported the ENBs. We then explore the students' interview responses and ENBs, and illustrate their use of the ENBs through a sample notebook entry. These three data sources allow us to characterize the different perceptions and uses of the ENB in each class. We conclude with a summary that looks across the classes and a discussion of educational implications.

Mr. S

At the time of this study, Mr. S had been teaching for 10 years. He began as a chemistry teacher and shifted into teaching engineering and robotics 3 years prior to the study's beginning. At the time of the study, Mr. S taught only engineering and robotics courses. He used robotics as an avenue for students to study engineering concepts and skills, such as design processes, Computer Aided Design, electronics (i.e., sensors), and programming. The class we examined was a Robotics I class taken by students ranging from 9th–12th grade. At the time of the study, students were working in groups to solve a complex, ill-structured, engineering challenge. In particular, his students were working towards a semester-long goal of creating a robot to participate in a VEX [34] competition.

Mr. S required that his students maintain individual ENBs and, early in the semester, he described the organizational methods he expected them to use, including: a table of contents, dates, page numbers and entry headings. In the early phases of their project, Mr. S explicitly identified particular activities as being things students should record in their ENBs, including: brainstorming, note-taking, design drawings, and formulations of strategies they might employ during the competition. When the class switched from idea-generation to building robots, Mr. S rarely explicitly mentioned ENBs.

An excerpt from one representative ENB (Carl's) is provided in Figure 2.

The top of Carl's entry contains a list of the basic requirements of the robotics challenge, labeled "What we need," as well as a list of how they could address the requirements, titled "What we want." The middle section is a concept sketch of how they might fulfill those "wants." A refined list of Carl's "wants" that includes references to specific parts and mechanical concerns (i.e, weight versus speed) is found beneath the sketch. These lists are not long, and, combined with ongoing group discussions, could easily be committed to memory. As such, as the physical robot began to take form, these students had little need to refer to their ENB entries.

In fact, in the interviews, all four interviewed students reported that they stopped referencing their journals when they started building. Carl stated that he referenced the journal "…a lot at the beginning of the year. As the season [semester] went on, I stopped looking at it as much… [because] I guess I lost track of trying to keep the designs going on…" Carl and his team apparently switched from working to execute the design in the ENB to designing "on-the-fly" in response to challenges they were facing with the physical robot. Moreover, they did not record these immediate, in-the-moment designs in their ENBs. In addition, Mr. S's students' interview responses aligned with Mr. S's depiction of the ENB as being emphasized only during idea generation: 3 of the 4 interviewees discussed using their ENBs to support idea generation, while the fourth student, Jeannie, reported completing her ENB retroactively to fulfill the assignment requirements but not using it during the actual design work.

The students also reported that their ENBs had limited use. For example, in response to a direct question about whether the ENB was useful, Jeannie said, vaguely, "I guess it was…." while Amy said that it helped them to "know what we're building." Amy went on to say that the ENB could have been more useful if they had drawn more pictures and used it more frequently. Another student, Donald, suggested that his journal would have been more useful if he had started with a better understanding of the parts they would be using and how they fit together. This comment points out a possible challenge facing these students when using their ENBs to facilitate idea generation: the students did not know enough to draw detailed sketches (see the lack of detail in Figure 1). However,

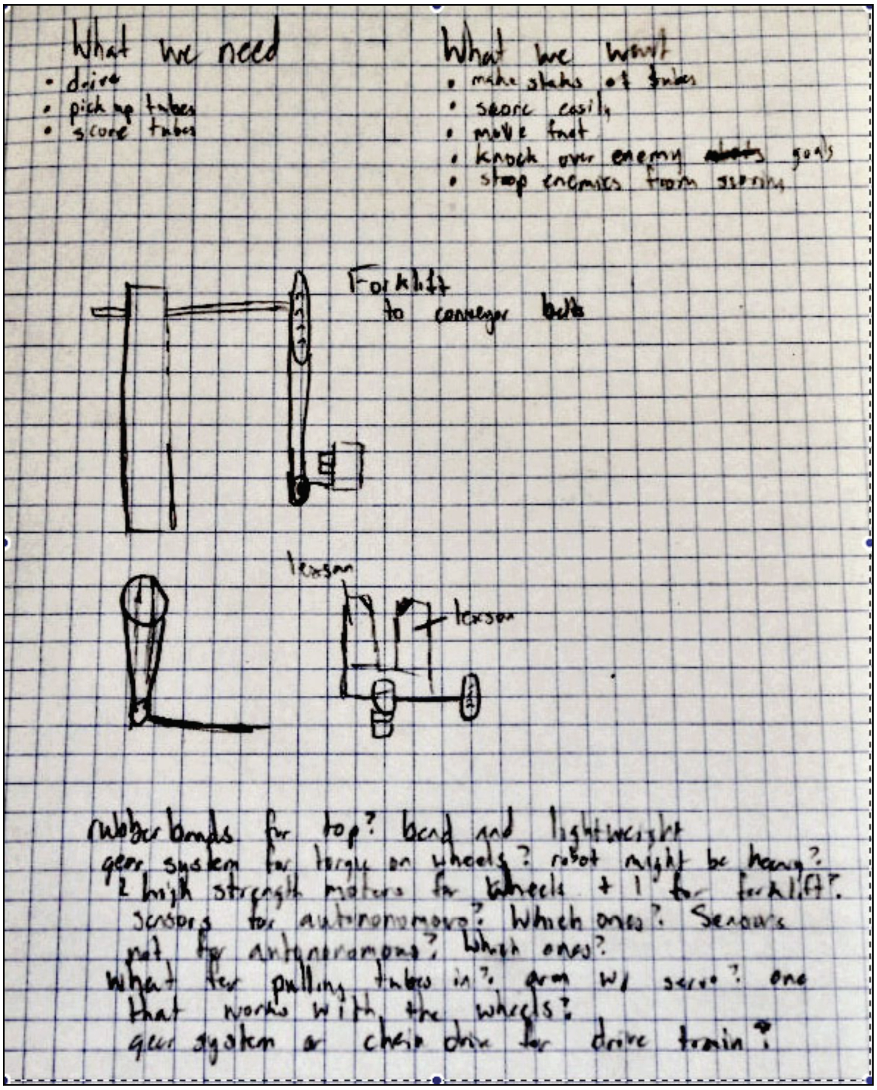

Figure 2. Excerpt from a representative ENB in Mr. S's class.

once they had enough familiarity with the VEX [34] robotics kits to create useful sketches of their design plans, they were no longer making regular ENB entries.

The students' ENB entries align with the interviews by revealing the challenge with making detailed drawings as well as the emphasis on the early part of the design process. First, as depicted in Carl's ENB (figure 1), the entries were rather sparse both in content and count. Secondly, consistency in the content and form of the individual ENB entries across students, suggests that each entry was the result of particular assignments made during the idea generation phase of the project. It therefore appears that the students primarily used their ENBs only when told to do so.

That said, entries from assignments were not without utility. For example, the drawings, although simple, supported cross-group communication. For instance, Donald reported that he used ENBs to "draw sketches on there so that you can show people how your robot would look later on…." In addition, the students reported referring back to the strategy notes that they took early in the semester.

In contrast to the students' perceptions and experiences of the ENB, Mr. S began the semester hoping that they would record exercises, notes, ideas, sketches and reflections in their ENBs and that the ENBs would be "an official record of their activities." However, Mr. S was well aware that the ENBs did not fulfill this purpose. In his interview, Mr. S commented that he "did not emphasize the importance well enough to make them worthwhile." Moreover, he stated that the students' end of semester design reports revealed no references to their journals. Instead they showed the students producing a "fresh eye analysis of their robot." This suggested to Mr. S that the ENBs had little value for the students, at least in term of facilitating design analysis.

Mr. O

The second class with which we worked was Mr. O's engineering course. The study was conducted during Mr. O's second year of teaching and his first year teaching engineering. Like Mr. S's class, Mr. O's students were building robots to compete in a local competition. In this case, the students were working towards the FTC [16] competition. Although Mr. O's class was engaged in a semester-long robotics project similar to Mr. S's class, the classroom activities were notably different. In particular, the design and build process were much more teacher guided.

With respect to the ENB, Mr. O provided the students with many more explicit guidelines than did Mr. S. In fact, he gave them a template for each ENB entry (exemplified in Figure 2) and asked them to complete one each class day. This template was for online ENBs that used Google Docs™, and was a modification of an FTC competition ENB template. The template focused on identifying tasks to be completed and capturing successes and challenges with each task.

Figure 3 contains an excerpt from Jason's team's ENB that is indicative of most of the ENB entries, with one exception: While tasks, reflections, and task details were included and provided them an accurate record of their plans across all entries, photographs were technically difficult to insert into the ENB's. As such they were rarely included.

Consistent with the template, all 4 of the students interviewed in Mr. O's class mentioned using their ENBs to document their design plans. For example, Jason stated that the ENB served as an "up-to-date reference of what we've been working on in the past week and what we're currently working on." Similarly, Mark described the ENBs as being a place to record "what we're planning on doing; what we did to our robot that particular day…."

DATE 12/10/2010 TIME SPAN 9:00 am - 10:26 am
TOPIC: re-wire robot and begin counter-balance for forklift

Tasks:	Reflections:
re-wire all of the controls so that they are mounted on the bottom of the pad	that took a while to finish. We ended it about halfway through the period
add a counter-balance to the forklift so the servos will actually be able to lift it	we had to raise the forklift up a little bit to get it to work, but it should suffice for now

TASK DETAILS: find a way to mount everything on the bottom without getting in the way of each other; find a way to add the counter-balance to the forklift itself,

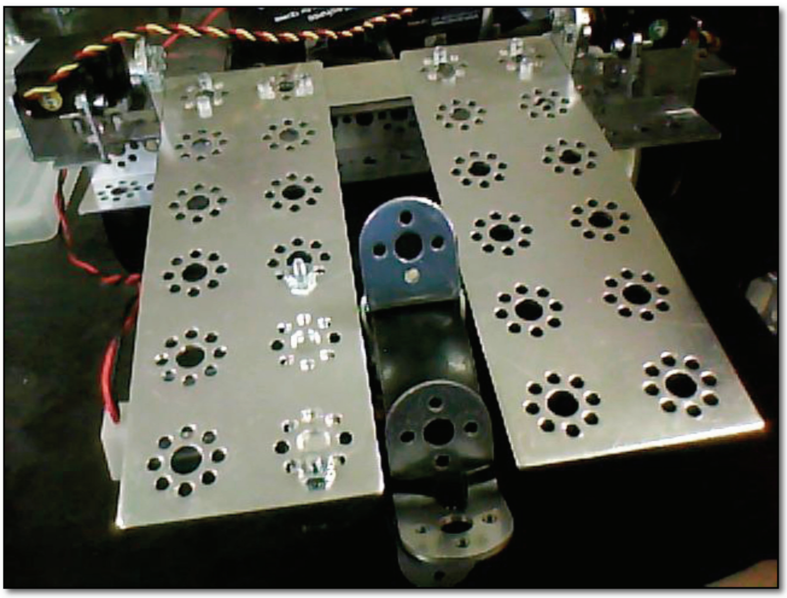

Figure 3. Excerpt from a representative ENB in Mr. O's class.

When discussing how the ENBs helped them, the students focused on two aspects: 1.) It could support their planning and 2.) They could look back at it to support future work. For example, Mark stated that when they are recording in the ENB they "decide what we're going to do for that day and then try to do it." The other 3 interviewed students also stated that the ENB supported reflection. For instance, Reba stated that the ENB was useful because "We can look back at it, see what we did and how far we've gotten and what we thought about it." Mr. O's students also saw the ENBs as useful for their teacher. For example, 3 of the 4 students mentioned that Mr. O graded their ENBs. Thus,

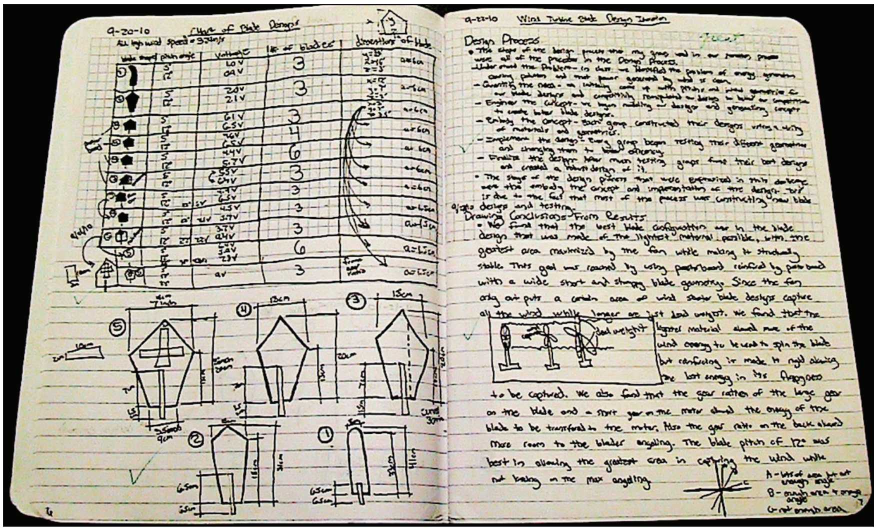

Figure 4. Excerpt from a representative ENB in Ms. M's class.

although they saw the ENBs as clearly being an assignment, Mr. O's students recognized that their ENBs were useful. In fact, when asked about this directly, Jason stated "Yes, absolutely useful."

However, while the students discuss the ENBs in terms of fulfilling multiple purposes (planning, reflecting and assessment), examining the student ENBs reveals that they focused primarily on the planning capabilities of the ENBs. Beyond identifying whether a task was completed (as seen in Figure 3), very few entries included reflection that could support students learning from previous struggles. That said, while the trend in this class was to provide few *detailed* reflections, students would occasionally do so. For example, Jason and John's group set a task to "program robot to autonomously traverse the makeshift bridge and balance the center" with a corresponding reflection that the "program should move forward a certain distance and then stop, hopefully balancing on…." They go on to note: "There is a small 'step' (sic.) present at the end of the bridge possibly causing an issue of traction with the mats. It is also important that the robot moves the right distance so that it can balance on the bridge."

Across these interviews and the students' ENBs we see a focus on planning that supported students in recording their daily activities for the class period. Thus, unlike Mr. S's students, we see that this class used their ENB in a way that supported the build phase of their design work. Mr. O similarly characterized the ENBs as supporting the students by helping them plan. However, he added to this an expectation that the ENBs would support reflection stating that he wanted students to use their ENBs to "chart their progress along the way…so that they could reflect on where they came from." In addition, the template he provided his students emphasized both planning and reflecting by asking students to identify tasks and record successes and challenges with those tasks.

However, similar to Mr. S's students, Mr. O's students struggled with recording how and why their designs changed over time.

Ms. M

At the time of the study, Ms. M, the third teacher with which we worked, had been a teacher of science and technology courses for 9 years; this was her second year teaching engineering. Ms. M was enacting a pilot version of a university-developed engineering course. This course involved multiple, 6-week long design challenges. The challenges were devised to create opportunities for students to: make innovative designs; learn design processes; and test and iterate upon their ideas.

Consistent with the curriculum, Ms. M required that her students maintain individual process-based ENBs. Unlike the other teachers, Ms. M both provided explicit instructions and expectations for each ENB entry and set-aside class time for students to focus on completing the ENBs. In general, she expected the ENBs to be separated into sections that represented the different design challenges and that all project work would be recorded in the ENBs. In particular, Ms. M asked students to record their work on each of the explicit assignments and data collection activities that supported their design work. In addition, prior to our interviews, Ms. M lead a brief class discussion about the utility of ENBs in professional practice (this emphasized the importance of securing intellectual property) and showed students images of professional ENBs.

Three of the four students interviewed in Ms. M's class described using their ENBs as a place to record their project work for an outside evaluator (e.g., a teacher or patent officer). For instance, Susan stated that she used her ENB to record notes, data charts, sketches and responses to teacher questions. Susan explained that the class was completing the ENBs because "when making like a patent, they have to be able to understand it." Susan's responses suggest that her ENB was not intrinsically useful for her—she did not see it as a tool to support her work on the project. Instead, Susan seemed to view the ENB as a way to learn engineering practices, and as an artifact to be assessed by outsiders. In fact, only one student in Ms. M's class, Allen, described the ENBs as a tool that supported his work on the design challenges. Allen stated that the ENB was for "me, so that I have a place I can go to whenever I need info about a project."

The students' emphases—as they came across in the interviews—are apparent in the ENBs themselves. In fact, the four ENBs we examined were incredibly consistent in the information included and their formatting. The information included lecture notes, empirical data, judgments regarding their data relative to the project at hand, and descriptions of their design solutions. Allen's ENB (Figure 4) exemplifies the content and formatting seen in the ENBs of Ms. M's students.

Class	Student perception	Teacher Perception	Use of ENB	Challenges
Mr. S	Supported idea generation, but not very useful.	Hoped they would be a record of student work in the progress but only supported them through the idea generation phase.	Entries were sparse, lacked detail, and were focused on the idea generation phase of the project. Few entries discussed design changes over time.	Students struggled with creating drawings that reflected the constraints of the VEX kit. Students did not see ENBs as useful during build. Few entries discussed design changes over time.
Mr. O	Some students perceived the ENB as useful for planning the day's activities. Few students recognized its utility in supporting reflection or learning from work the previous day.	Wanted students to record their progress, problems and solutions to support their reflection.	Focused on identification of immediate tasks. Students struggled with recording design changes.	Few entries discussed design changes over time.
Ms. M	ENBs are for recording all of your work so teachers and patent officers can assess it.	Wanted students to experience the professional practice of careful record keeping and to reflect on their progress.	All four students had ENBs that were similar in content and formatting suggesting a focus on completing assignments. ENBs reflected a very thorough record of their work.	The focus on assessment or evaluation meant that students rarely saw the ENB as useful to their progress, and their entries, consequently, did not record the evolution of their design ideas.

Table 1: Summary of the analysis.

The consistency in content and formatting across students suggests that they were told what to put in their ENBs. Moreover, the focus on data suggests that the ENBs were used to test and explore different aspects of the designs more than for idea generation.

The students' focus on carefully documenting all of their work aligned with Ms. M's purpose for the ENB: "Students in the engineering science course are asked to use ENBs to fully document their work in order to experience and practice this procedure…[I hope that] they will experience a real-world process that involves documenting their work thoroughly." However, the students' focus on complete records did not fulfill Ms. M's hopes for this assignment. In fact, Ms. M stated that she wanted "the journals to be more than just lab books for answering questions." Instead, she wanted the students to "document their ideas as well as just 'answers' to lab questions or reflections."

DISCUSSION

Table 1 summarizes our characterization of student and teacher perceptions of the ENBs as well as how students used them and the challenges therein.

As seen in Table 1, each class engaged with the ENB differently. This is not surprising, given the variety in the classrooms and curricula enacted. However, even with these stark differences, four themes emerge from their commonalities:

1. All three classes produced process-based ENBs
2. The different styles of ENBs supported different phases of the design process.
3. It was difficult to support student reflection about their evolving designs.
4. Students recognized the utility of their ENBs.

We discuss each of these themes below, concluding with instructional implications.

Theme 1: Focus on process-based ENBs

Across the classes, we see a focus on process-based ENBs instead of product-based. That is, students were asked to record information supporting their work-in-progress, rather than their final form design solutions. This consistent focus on process-based ENBs, despite the extreme differences in usage exhibited in this study, suggests that process-based ENBs may align more closely with engineering high school teachers' goals and needs than product-based ENBs. Though the power of process-based ENBs has been documented in other domains, a larger study is needed confirm their usefulness in contributing to deeper understanding in high school engineering classes.

Theme 2: Different ENBs differentially support particular phases of the design process

Although all of the ENBs focused on the students' processes, the different ENB uses that emerged in this study align with different stages of a design project. The ENBs in Mr. S's class supported idea-generation; Mr. O's class produced an ENB for building; and the ENBs in Ms. M's class best supported product testing. (To be fair, the ENBs in Ms. M's class were designed to record the lifecycle of the project, but, as discussed above, student entries heavily emphasized the data collection steps). These results suggest that students (and teachers) may struggle with maintaining a single ENB across the very different phases of an engineering design process (over the lifecycle of an entire project). In fact, Ms. M recognized this challenge in her interview in which she stated "One big change I plan to make for next year is more step-by-step guidelines for using the ENB to document different types of activities—lab versus notes versus design."

The teachers' support of the ENB provides some insight into this phenomenon. Mr. S explicitly emphasized all forms of idea generation as ENB material, and he admitted to only focusing on the ENBs during the idea generation phase. Mr. O on the other hand provided very explicit ENB guidelines supporting the building phase of the project. Finally, Ms. M expected students to record their project work on the explicit assignments in their ENBs with an emphasis on supporting data.

Thus, when looking back at the context in which students were creating their ENBs, we can see that teacher support and expectations play a large role in the resulting use of the ENBs.

Theme 3: Challenge of supporting design evolution reflection

The third theme that emerged related to the challenge of supporting student reflection regarding the evolution of their designs. For example, Mr. O provided his students with a template that emphasized reflection, but his students rarely engaged in that task. Instead, they focused on answering the more concrete questions regarding their plans for the day. Ms. M's very explicit instructions, intended to initiate reflection, promoted consistent ENBs across the students but did not foster student reflection on their progress. This suggests that explicit instructions may not be the best technique for supporting student reflection on their design progress. However, we also see that Mr. S provided little support for reflection and his students' ENBs reveal a similar lack of depth. This then raises questions about how to best support student reflection.

Theme 4: Students recognize ENB's utility

Despite the difficulties mentioned in the second and third themes, the final emergent theme is that the students recognized the utility of their ENBs. However, their perception of the utility was intricately connected to the content they recorded in their ENBs. Mr. S's students seemed to recognize that recording design ideas is a useful way to converge on an idea. Similarly, Mr. O's students recognized that their ENBs could support planning. Finally, Ms. M's students discussed the importance of having a complete record—particularly of their empirical data—for later review.

Implications for instruction

The final theme suggests a solution to the challenges identified in the earlier themes: if we want students to use their ENBs throughout the lifecycle of their design projects, and to reflect on how their designs changed throughout that process, they must experience that recording as useful. While one might be able to mandate ENB content and format that would require students to maintain their ENBs throughout the projects (as Ms. M did), it is difficult to provide explicit instructions that motivate their reflection (as Ms. M and Mr. O found). Rather, we propose that the solution involves creating situations in which documenting their project work and reflecting on how the designs have changed over time serves a purpose for the student—so they experience it as useful.

This proposal aligns with research that suggests that students' perception of their task influences the ways in which they perform those tasks [4]. For example, Berland and Reiser [5] found that the ways in which students engaged in the communicative practice of scientific argumentation differed depending on whether they believed they were attempting to demonstrate their own knowledge or to win a debate. In addition, researchers in communication demonstrate that student's written products change depending on the perceived audience [28,29,31]. Similarly, Forte and Bruckman [17] demonstrated that students used more technical vocabulary and were less rigorous with their citations when writing for their teacher than an external Internet audience.

Thus, the key instructional implication of this work is that facilitating students meaningful and thorough use of their ENBs requires creating situations in which maintaining these ENBs is a useful task such that this record helps the students complete their project work. Each of the individual teachers offers insight into how to do this. In Mr. S's class we see that discussing sketching and using the ENBs as a repository for their initial design ideas gives students an anchor in which they can root their later design discussions. Then, Ms. M's students experienced the data tables as useful—they were an information source to which the students could refer throughout their design process. Finally, the focus on planning in Mr. O's class created a meaningful use for the ENBs during the build phase of the project. Thus, it might be that supporting student use of these ENBs throughout the project lifecycle requires emphasizing their shifting utility.

A note of caution: key to this study and the instructional implication is the expectation that students will perceive their ENBs as useful. Thus, the work that students do in the ENBs must be complex enough that they would be unable to perform the same brainstorming, data analysis and referencing of that data, and planning, without the ENBs. That is, if we expect students to experience their ENBs as useful throughout the lifecycle of their project, teachers must do more than ask students to engage in these different tasks: teachers must facilitate design challenges that student will be unable to successfully complete without maintaining a thorough ENB. We see pieces of this in each of the classes studied: Mr. S's design challenge was free-form enough that students needed to sketch their ideas in order to communicate them; Ms. M's data collection activities generated enough useful data that students needed to be able to reference it later in their processes; and Mr. O's students were building a robot with many subcomponents that students need to coordinate. Thus, the trick becomes maintaining this necessity of the ENBs throughout the design project.

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