AC 2011-2494: UNDERSTANDING STUDENTS' PERCEPTIONS ON THE UTILITY OF ENGINEERING NOTEBOOKS

Leema Kuhn Berland, University of Texas, Austin

Leema Berland is an assistant professor of science education at the University of Texas in Austin. She earned a Ph.D. in the Learning Sciences from Northwestern University in 2008 and was a doctoral fellow with the NSF funded Center for Curriculum Materials in Science (2003-2008). Leema is broadly interested in facilitating and studying students as they engage in complex communication practices. She is currently focused on exploring the dynamics of how and why students are able (or unable) to productively communicate in engineering classrooms, in the context of UTeach Engineering high school classrooms.

William F McKenna, University of Texas at Austin

Bill received his masters of mathematics from the University of North Texas about ten years ago, and after a brief but potentially promising career in acoustical test enclosures, he is working in his fourth year towards a doctorate in Science and Mathematics Education. Helping to make the world a quieter place is a fine and noble thing, but it simply does not compare to educating people. These days Bill focuses on communication in technical fields. His current research involves helping high school students learn the form, function and benefits of effective communication, especially argumentative discourse and interpersonal relations.

Stephanie Baker Peacock, The University of Texas, Austin

Stephanie received her BS and MS of Mathematics at branch campuses of The University of Texas and is pursuing her PhD in Science and Mathematics Education at The University of Texas at Austin. Her predominate research interest focuses on development of algebraic reasoning and symbolic understanding. Special attention is paid to students in community college developmental math courses and their transitions to credit-bearing courses, and issues encountered by English Language Learners and persons of low socioeconomic status. She is broadly interested in access to science, technology, engineering, and mathematics education at all grade levels.

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Understanding students' perceptions on the utility of engineering notebooks

Engineering notebooks—also called portfolios or journals—are pervasive in college and high-school engineering courses[1,5,6,7,8,9,10,16,17,19]. 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[18]. The engineering education community therefore appears to have embraced engineering notebooks. This paper is a preliminary exploration into high school teachers' and students' perceptions of these notebooks.

Types of engineering notebooks

A brief review of the literature reveals that engineering notebooks can take many forms and be used for many purposes. For example, Tillema and Smith (2000)[24] identified three distinct types:

1. A dossier is a notebook 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" (p. 194)[24].
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 (1996)[22] 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 notebooks 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 (1999)[24] offer a simpler taxonomy with two types of notebooks, "representational" and "developmental portfolios". Similarly, Christy and Lima (1998)[8] differentiate between notebooks 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 notebooks record *products* or record *processes*. In this paper, we discuss notebooks in terms of the product versus process distinction.

Since there are multiple possible purposes, forms, and outcomes of engineering notebooks, we expect that engineering teachers and students may have different perceptions of their notebooks and beliefs about what content should be included therein. After providing more detail about the distinctions between product- and process-based notebooks, we will discuss how we studied the possibility of such diversity by examining student and teacher perceptions of engineering notebooks.

Distinctions between product- and process-based notebooks

Product- and process-based engineering notebooks 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 portfolios: perceived audience and when reflection and feedback occurs. When completing product-based notebooks, students select and record their products upon completion of a project or course. While the selection and feedback process can foster student reflection, these notebooks are typically an opportunity to demonstrate competency. Thus, external evaluators become the primary audience of product-based notebooks. In contrast, process-based notebooks are for recording, reflecting upon and receiving feedback on works-in-progress. Creators of process-based notebooks are meant to include preliminary ideas, personally relevant questions, and justifications of decisions made. Consequently, while an instructor might also evaluate process-based notebooks, the primary audience is the author: the notebook is a resource to support the author's progress on his or her design work. We provide examples of both notebook types below and offer a brief discussion of their value for supporting student learning.

Product-based portfolios are used to record final form projects. McKenna, Colgate, Carr and Olson[19] 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 (p. 673)." Knott et al.[16], provide an additional example of a product-based notebook in their study of the effectiveness of ePortfolio software. In this case, the students used the portfolios as an opportunity to record final products and biographical information (e.g., resumes), as if the notebooks were for future job applications or similar activities. These 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. Product-based engineering notebooks, such as these, are used primarily for student evaluation and can 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.

Process-based notebooks are much more varied across instantiations and current research does not provide clear descriptions of intended notebook contents. For example, Anderson-Rowland, Reyes and McCartney[1] offer a vague specification of contents of a process-based engineering notebook stating that they included "participant documentation of the process they used to arrive at their final design" (p. 4). An example of one of the clearer specifications comes from Lackey et al.'s[17] work in which students are asked to include two columns in their notebooks, 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,[15] and it is argued that they support learning. For example, Eris[10] argues that process-based engineering notebooks 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 place. 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 (p. 556).

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

Work in other content domains, on the other hand, demonstrates that process-based notebooks can support student learning by mediating student conversations, making their thinking visible and providing an opportunity for them to connect course material to the real world. For instance, in a study of how students in an advanced high school physics course used their "learning logs," Audet, Hickerman and Dobrynina[2] 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[11] related student success to their knowledge of the content, the model revision processes, and their own problem solving process. These items were recorded in the students' notebooks. Finkel's work suggests that the students' notebook supported the students' learning by making their problem solving processes explicit and visible. In addition, Jensen and Harris[14] 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 interpret engineering notebooks, we examined the use of engineering notebooks in 3 high-school engineering classes. Students in each class were expected to maintain an engineering notebook. 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 interpretations of the engineering notebooks.

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 notebooks. The classroom observations were used to provide an overall sense of each classroom environment. For each class, we interviewed and examined the notebooks 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 engineering notebooks. Interpretations of the content of each student's notebook were used to determine whether stated perceptions aligned with their actual use of the notebook. Taken together, the interviews and engineering notebooks provided different lenses into the how engineering notebooks were used and perceived in each of the participating classes.

The engineering notebooks 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 and conducted one-on-one. Students had access to their own notebooks and teachers had access to excerpts of selected student notebooks during the interviews.

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)	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 notebooks? 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. 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.)	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

Analysis of these three data sources (student interviews, teacher interviews and notebooks) focused on finding patterns within a student's responses to the questions and their work with the notebooks, and across students and teachers in a particular class. We started by examining 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 notebooks. We then compared these themes to the individual's notebook. For example, if a student reported using the notebooks to record design ideas, we looked in that student's notebook to see if they, in fact, did so.

After the individual analyses, 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 notebook'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.

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 iterated through our analyses of the individual student- and teacher- interviews. 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 engineering notebooks 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 engineering notebooks. We then explore the students' interview responses and engineering notebooks. These three data sources allow us to characterize the different ways in which students and teachers in each class interpreted the engineering notebooks. 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. Mr. S taught only engineering and robotics courses. He used robotics as an avenue for students to study engineering concepts and skills, namely: design processes, Computer Aided Design (CAD), electronics (sensors) and programming. The class we examined was a Robotics I class taken by students ranging from 9^{th}-12^{th} grade. Mr. S designed the curriculum of the first semester (the focus of our study) to engage students in solving one complex, ill-structured, engineering challenge. In particular, his students were working towards a long-term goal of creating a robot to participate in a VEX[25] competition.

Mr. S required that his students maintain individual engineering notebooks and, early in the semester, he described the organizational methods he expected them to use, including: a table of contents, dates, page numbers and headings for each entry. In the early phases of their project work, Mr. S explicitly identified particular activities as being things students should record in their notebooks, 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 reduced his focus on the notebooks.

In the interviews, Mr. S's students' comments reflected this focus on the early phases of the design project. In fact, 3 of the 4 interviewees discussed using their notebooks to support idea generation, and all four 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 notebooks 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 notebooks. The fourth student, Jeannie, reported completing her notebook retroactively to fulfill the assignment requirements but not using it during the actual design work.

The students reported that their notebooks had limited use. For example, in response to a direct question about whether the engineering notebook 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 notebook 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 notebooks to facilitate idea generation: the students did not know enough to draw detailed sketches. However, once they had enough familiarity with the VEX robotics kits to create useful sketches of their design plans, they were no longer making frequent notebook entries.

The students' notebook 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, we see that the entries were rather sparse both in content and count. Donald's notebook exemplifies this with concept drawings taking up less than half of a page in his notebook. While a crude measure, this suggests that the drawings lacked details. Secondly, the notebook entries were clearly the result of particular assignments made during the idea generation phase of the project: the students primarily used their notebooks when they were told to do so.

That said, entries from assignments were not without utility. For example, the drawings, although very simple, supported cross-group communication. For instance, Donald reported that he used notebooks 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 notebook, Mr. S began the semester hoping that they would record exercises, notes, ideas, sketches and reflections in their notebooks and that the notebooks would be "an official record of their activities." However, Mr. S was well aware that the notebooks 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 notebooks 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[12] 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. In addition, Mr. O provided the students with many more explicit guidelines regarding their notebooks: Mr. O required that each team complete on-line engineering notebooks using Google Docs™ and a template that he provided (see Appendix A). This template was a modification of an FTC competition notebook template and focused on identifying tasks to be completed and capturing successes and challenges with each task.

Consistent with the template, all 4 of the students interviewed in Mr. O's class mentioned using their notebooks to document their design plans. For example, Jason stated that the notebook 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 notebooks as being a place to record "what we're planning on doing; what we did to our robot that particular day…."

When discussing how the notebooks 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 notebook they "decide what we're going to do for that day and then try to do it." The other three students also stated that the notebook supported reflection. For instance, Reba stated that the notebook 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." In addition, all four students discussed using the notebook of a more advanced robotics team in their own design work. In this case, Mr. O's students recorded the previous team's successes and failures and referred to them throughout their own robotics design challenge. Mr. O's students also saw the notebooks as useful for their teacher. For example, 3 of the 4 students discussed Mr. O grading their notebooks. Thus, although they saw the notebooks as clearly being an assignment, Mr. O's students recognized that their notebooks were useful. In fact, when asked about this directly, Jason stated "Yes, absolutely useful."

Mr. O similarly characterized the engineering notebooks as supporting the students by helping them plan and reflect. He stated that he hoped the engineering notebooks would help students "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, while the students and teacher discuss the notebooks in terms of fulfilling multiple purposes (planning, reflecting and assessment), examining the student notebooks reveals that they focused primarily on the planning capabilities of the notebooks. Very few entries supported reflection or the possibility of learning from previous struggles. For example, Jason and John's journal contained the task entry of "creating an autonomous program that will balance the robot on the bridge." Then, in the reflection section of their entry they reported (presumably at the end of that class day): "Attempted to create working autonomous program. Came across difficulties." This level of reflection might support planning in subsequent days as it suggests that the autonomous program task was incomplete. However, it provides no details that might enable these students to rectify the struggles they faced. Reba and Mark's notebook provided similar examples of planning entries that appear not to have enough detail to help them solve the particular problems they encountered.

It is important to note that, while the trend in this class was to provide few detailed reflections, students would occasionally include notebook entries that were detailed enough to help them learn from their past experiences. 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 this class we see a focus on planning that supported students recording their daily activities for the class period. Thus, unlike Mr. S's students, we see that this class used their notebook in a way that supported the build phase of their design work. However, similar to Mr. S's students, these students struggled with recording how and why their designs changed over time.

Ms. M

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 notebooks. Unlike the other teachers, Ms. M both provided explicit instructions and expectations for each notebook entry and set-aside class time for students to focus on completing the notebooks. In general, she expected the notebooks to be separated into sections that represented the different design challenges and that all project work would be recorded in the notebooks. 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.

Three of the four students interviewed in Ms. M's class described using their notebooks 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 notebook to record notes, data charts, sketches and responses to teacher questions. In her discussion of sketches, Susan stated that they did not need to be "fabulous sketches or anything, but they need to be in there." In addition, Susan explained that the class was completing the engineering notebooks because "when making like a patent, they have to be able to understand it." Susan's responses suggest that her engineering notebook 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 notebook as a way to learn engineering practices, and as an artifact to be assessed by outsiders.

Only one student in Ms. M's class, Allen, described the notebooks as a tool that supported his work on the design challenges. Allen stated that the notebook was for "me, so that I have a place I can go to whenever I need info about a project." However, even with the different perceived audience, Allen reported recording similar information in his notebook. He focused on empirical evidence and class notes or, in his words "data about different aspects of the project."

The students' emphases—as they came across in the interviews—are also apparent in the engineering notebooks themselves. In fact, the four engineering notebooks we examined were incredibly consistent in the information included and the formatting of the notebooks. The information included lecture notes, empirical data, judgments regarding their data relative to the project at hand, and descriptions of their design solutions. The consistency in content and formatting suggests that students were including information in their notebooks to fulfill an assignment, suggesting that they were told what to put in their notebooks and how to put it there. Moreover, the focus on data suggests that the notebooks were used to test and explore different aspects of the designs more than for idea generation—as they were in Mr. S's class.

The students' focus on carefully documenting all of their work aligned with Ms. M's purpose for the engineering notebook: "Students in the engineering science course are asked to use notebooks 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 engineering notebooks as well as how students used them and the challenges therein.

Class	Student perception	Teacher Perception	Use of notebook	Challenges
Mr. S	Supported idea generation, but not very useful.	Hoped they would be a record of student work in the progress but	Entries were sparse, lacked detail, and were focused on the idea generation phase of	Students struggled with creating drawings that reflected the constraints of the

		only supported them through the idea generation phase.	the project. Few entries discussed design changes over time.	VEX kit. Students did not see notebooks as useful during build. Few entries discussed design changes over time.
Mr. O	Some students perceived the notebook 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	Notebooks 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 notebooks that were similar in content and formatting suggesting a focus on completing assignments. Notebooks reflected a very thorough record of their work.	The focus on assessment or evaluation meant that students rarely saw the notebook as useful to their progress, and their entries, consequently, did not record the evolution of their design ideas.

Table 1. Summary of the analysis

As seen in Table 1, each class engaged with the engineering notebook differently. This is not surprising, given our search for variety across the classes. However, even with these stark differences, four themes emerge from their commonalities:

1. All three classes produced process-based engineering notebooks
2. The different style of notebooks 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 notebooks.

We briefly discuss each of these themes below, concluding with their implications for instruction.

Theme 1: Focus on process-based engineering notebooks

Across the classes, we see a focus on process-based engineering notebooks 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 notebooks, despite the extreme differences in usage exhibited in this study, suggests that they may align more closely with engineering high school teachers' goals and needs than product-based notebooks. Though the power of process-based notebooks has been documented in other domains, a larger study is needed to verify both that process-based engineering notebooks are consistently emphasized over product-based notebooks and to solidly confirm their usefulness in contributing to deeper understanding in high school engineering classes.

Theme 2: Notebook style supports particular phase of design process

Although all of the notebooks focused on the students' processes, the different notebook uses that emerged in this study align with different stages of a design project. The engineering notebooks in Mr. S's class supported idea-generation; Mr. O's class produced a notebook for building; and the notebooks in Ms. M's class best supported product testing. (To be fair, the notebooks 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 notebook 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 notebook to document different types of activities—lab versus notes versus design."

The teachers' support of the notebook provides some insight into this phenomenon. Mr. S explicitly emphasized all forms of idea generation as notebook material, and he admitted to only focusing on the notebooks during the idea generation phase. Mr. O on the other hand provided very explicit notebook guidelines supporting the building phase of the project. Finally, Ms. M expected students to record their project work on the explicit assignments in their notebooks with an emphasis on supporting data. Thus, when looking back at the context in which students were creating their notebooks, we can see that teacher support and expectations play a large role in the resulting use of the engineering notebooks. Looking at the physical notebooks also exhibits these relationships.

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 notebooks 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. Suggestions related to ways to foster reflection are offered below.

Theme 4: Students recognize notebook'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 engineering notebooks. However, their perception of the utility was intricately connected to the content they recorded in their notebooks. Mr. S's students seemed to recognize that recording and evaluating design ideas is a useful way to converge on an idea and that the sketches could be used during the building phase of their work. Similarly, Mr. O's students recognized that their notebooks 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 notebooks 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 notebook content and format that would require students to maintain their notebooks 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 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 is key to the ways in which they perform those tasks. For example, Berland and Reiser[3] found that 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[20,21,23]. Similarly, Forte and Bruckman (2009)[13] demonstrated that students used more technical vocabulary and were less rigorous with their citations when writing for their teacher than an external Internet audience.

The above analysis provides some insight into how teachers can influence student perceptions of the utility of their engineering notebooks. In particular, the multiple, sensible uses that emerged in these 3 classes, and the fact that each use aligned with different parts of engineering processes, suggests that it is difficult to design a process-based engineering notebook that effectively records the many and varied steps of an engineering project. As a result, we put forward that educators must carefully consider their goals for the notebook. Doing this would enable teachers to align their implicit expectations for the engineering notebooks with their explicit guidelines. In addition, explicit discussions of why professionals use notebooks may help students understand their purpose and giving students control over their process may help them to see recording that process as helpful. Finally, the emergent consistent emphasis on process-based notebooks underscores the need to understand the expectations associated with these broadly defined notebooks.

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Appendix A

Team #

DATE TIME SPAN

TOPIC:

Tasks	Reflections

TASK DETAILS:

REQUIREMENTS (IF ANY):

THOUGHTS (IF ANY):

PICTURES, DRAWINGS (IF ANY):