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Teacher Implementation of Structured Engineering Notebooks in Engineering Design-based STEM Integration Units (Fundamental)

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In the classroom, engineering notebooks allow students to develop their ideas, take notes, record observations, and reflect on what they have learned. Structured notebooks are used to help students engage with material at greater depth through analyzing questions, formulating predictions, and interpreting results. Notebooks are an important resource for teachers to formatively assess students' ideas. By incorporating notebooks into classroom instruction and using them to guide feedback to students, teachers can use notebooks to support student learning of engineering design in STEM integration.

This study investigates how teachers implement structured engineering notebooks within an engineering design-based STEM integration unit in upper elementary and middle school science classrooms. The study is guided by the research question: What are the variety of ways in which teachers implement structured engineering notebooks during an engineering design-based STEM integration unit? Results of four case studies and a cross-case comparison show that teachers often used notebooks as tools for class discussion or group work, and provided real-world examples of how notebooks represent the practices of professional engineers. Some teachers had students write in notebooks individually, while others used them for group or whole class discussion about concepts. The student notebooks in each of the classrooms had high or low completion and variety, and had evidence of students thinking individually or collectively.

Introduction

Engineering design is a unique process for each individual designer [1]-[4]. Therefore, engineering design is difficult both to assess for grading purposes and for teachers to understand their students' abilities. Engineering notebooks have the potential to be an effective formative assessment aid. Not only are notebooks used by practicing engineers and therefore their use is an authentic engineering skill, they also give students opportunities to formulate and record their ideas to maintain a record of their engineering design processes [5]. Therefore, they can be used by teachers to assess the processes that students use, not simply their end product [6]. However, to effectively use engineering notebooks for assessment purposes, students need support until they have become accustomed to using them [7], [8]. Certainly, the structure of the curriculum and the prompts in notebooks can encourage students to effectively notebook. However, the instructions that teachers give students will determine what students think is important, regardless of what the notebook instructions may say.

Teachers play a major role in the way students document their design process in notebooks [9]. Previous research found that, although the same instructions were given to all teachers regarding the notebooks, students' level of documentation varied considerably across classrooms [9]. This variety limited the investigation of students' notebook use and the feedback they were given by their teachers. As we practically approached the data for the study, we observed that many classrooms had notebook data that were simply unuseable for understanding students' design process. To realize the potential benefit of notebooking for engineering design assessment purposes, it is important to understand the specific contextual teacher factors that influence students use of them. A goal of this work is to add to the body of knowledge about how teachers can effectively implement engineering notebooks in their classrooms to capture students learning of engineering design content and skills. To explore teacher implementation strategies of the notebooks, we asked the following overarching research question: What are the variety of ways in which teachers implement structured engineering notebooks during an engineering design-based STEM integration unit? To address our research question, we used a multiple case study approach and a cross case analysis based on videos of teacher implementation and their students' notebooks.

Literature review

In science, technology, engineering, and mathematics (STEM), formative assessment is an integral part of high-quality instruction. The Next Generation Science Standards (NGSS) expect teachers to provide multidimensional science instruction of disciplinary core ideas, science and engineering practices, and crosscutting concepts [10]. This new type of instruction will determine the types of evidence they use to assess learning and make pedagogical decisions [11]. If teachers are investigating students' conceptual knowledge of engineering and science at this level of complexity, they must have assessment methods that can demonstrate learning beyond surface-level knowledge. To obtain a complete picture of student learning, the regular assessment of student learning, supplied by formative assessment within instruction, is integral to this educational design [12]. Formative assessment provides a quick check of learning using an informal approach. It is meant to be implemented throughout an educational unit, so teachers can continually adjust their instruction to ensure that all students reach the same level of understanding [13]. Frequent low-stakes checks of progress are useful to teachers and students by providing feedback that identifies individual learners' strengths and challenges [14]. In science, technology, engineering, and mathematics (STEM), formative assessment should be an integral part of instruction.

At the same time, formative assessment promotes self-regulation in students as they monitor their progress [15]. Formative assessment makes students aware of objectives and expectations, when it is accompanied by clear and meaningful feedback. Gedye [16] and Clark [15] discuss the concept of *formative feedback* that builds on assessment to initiate dialogue between teachers and students. According to Gedye [16], formative feedback will help students learn to self-assess by applying good assessment practices to evaluate themselves. From evidence gained through formative assessment, teachers will be prepared to give feedback and adapt instruction to individual students.

Notebooks have the potential to give teachers a way to flexibly assess science and engineering learning within an educational context. Because they are embedded in the curriculum as part of instruction, notebooks give specific data to guide formative assessment [17]. They help students monitor their own thoughts, and give them a space to construct knowledge through reflection. Notebooks are authentic to scientific and engineering practices, where they are used by professionals to hold plans, diagrams, schematics, and calculations [5]. Ownership is important to the authenticity STEM notebooks, and teachers should provide enough scaffolding for students to learn from using them, while also giving them autonomy [18]. From a study of engineering in elementary school classrooms, Hertel, Cunningham, and Kelly [8] concluded that student notebooks are able to scaffold engineering learning and epistemic practices of engineering. When science notebooks are used by teachers in an experienced way, they will be situated within structured learning experiences, and teachers will use the information collected by notebooks for dynamic understanding through collaboration [19]. However, this use may not always be reflected in teacher practice. In a study of teacher feedback around elementary and middle school science notebooks, Ruiz-Primo and Li [20] found that a minority gave comments, with even fewer prescribing future directions for students. Notebooks in science and engineering are more than just tools for students to record classroom activities or practice their language skills [18], although both are important. They can be a reliable formative assessment tool [21]. When implemented effectively, notebooks support activity by scaffolding students to more deep and complex observations, predictions, explanations, and reflections.

Methods

We used a case study methodology to explore the differences and similarities in how four middle school teachers implemented notebooks within an engineering design-based STEM integration unit. This method is useful for understanding a phenomena within a bounded context, where the behaviors of individuals are impacted by larger social dynamics [22]. It makes use of "a full variety of evidence" [22] that includes artifacts as well as interviews, direct observation, or participant-observation. Because the focus of the case study method is on the decisions, events, and processes of individuals and groups within a context [22], it is appropriate for our study of teacher implementation of structured engineering notebooks.

School contexts

We purposefully selected four teachers who participated in the teacher professional development for the engineering design-based STEM integration unit (with notebooks embedded) and then implemented the unit in their classes. The four teachers are Mrs. J, Mr. R Mrs. M and Mrs. P. Mrs. M teaches an advanced sixth grade class, and the other three teachers teach eighth grade. All four teach in different midwestern middle schools. Demographics for each school district are displayed in Table 1.

Table 1. School district demographics for teachers.

Teacher	**Grade Taught**	**School NCES Classification**	**% Students of Color**	**% Students in Free/Reduced Lunch**	**% English Language Learners** (District-wide)
Mrs. J	8^{th}	Suburban: Large	14.3	10.8	3.0
Mr. R	8^{th}	Suburban: Large	29.9	24.5	5.2
Mrs. M	6^{th} Advanced	Suburban: Large	22.6	12.7	2.8
Mrs. P	8^{th}	Suburban: Large	32.4	38.1	5.2

The students were presented with an engineering challenge through a letter from a client, and learned background science to be able to solve the challenge. In the engineering challenge for this unit, a train carrying minerals had derailed and fallen into a lake. Although the minerals had been recovered by the company in the scenario, they were no longer organized in an effective way. The client was asking the students to develop a process to sort the recovered minerals, based on the science of mineral properties they would learn in the unit.

Throughout the unit, the teachers were asked to have their students maintain structured engineering notebooks. Students recorded notes, ideas, drawing, and the responses to both science and engineering prompts. The engineering prompts were designed to scaffold students through the engineering design process. During this time, students recorded responses from both their individual work and during team work. They were asked to record their individual responses with a different colored pen than their individual responses.

This study focuses on initial problem scoping aspects of the unit, which for most of the classes was the first three days of the unit. During this time, the curriculum was written so that students used their notebooks in a variety of ways. First, students were introduced to the unit and told they would be working on an engineering design challenge. In their notebooks, students were asked to respond to two questions, “What do engineers do?” and “How do engineers solve problems?” They responded to these prompts both individually and as a team. Next, they recorded information about the engineering design process as instructed by their teacher. The activity involved students beginning their learning about mineral properties by looking at mineral samples and responding to the prompts “What do you notice/observe?” and “What do you wonder about?” as teams, and “Definition of a mineral” as a whole class. They then used a graphic organizer to record notes about minerals and how the properties related to the engineering design challenge. Finally, students responded to seven problem scoping prompts, namely “Who is the client?”, “What is the client’s problem that needs a solution?”, “Why is the problem important to solve?”, “Who are the end users?”, “What will make a solution effective (criteria)?”, “What will limit how you can solve the problem (constraints)?”, and “Think about the problem of minerals spilled into a lake. In terms of sorting the minerals, what do you need to learn in order to create a procedure to separate the minerals?” Students were asked to give both individual and team responses for each of the prompts.

Data collection and analysis

Each class was video recorded for the entire unit. Videos were recorded from a whole class perspective, as well as additional audio that focused on two target groups from each class. To examine each teachers’ implementation, we first individually watched the videos and recorded field notes of the format of their class and how they used notebooks in the class. The authors then came together to develop themes and relevant questions about the classroom implementation based on the field notes. These themes are recorded in Table 2.

Table 2. Classroom themes and descriptions.

Theme	Description
Lesson Elements	Each activity in the classroom, such as introducing the engineering design process, reading the client letter, and answering problem scoping prompts.
Notebook Use	Student notebook use during lesson elements, such as copying definitions or writing individual answers
General Setup of Notebooks	Presentation of notebooks to students. Ways that the teacher modeled notebook structure and format, such as having write directly in notebooks or pasting in worksheets.
Class Discussions	Use of student notebooks in whole class discussions by asking students to share their responses with the class.
Notebook Integration	Integration of notebooks with classroom instruction, such as amount of time and directions for writing in notebooks, use of deliverables, or small group discussion.

Real-Life Examples	Examples of engineering practice, especially of how engineers use notebooks in their work.
Notebook Storage	Storage space and/or student responsibility for notebooks, such as a designated classroom location or a team member to distribute them.

We organized each of the themes into a spreadsheet and recorded the relevant information for each teacher, relying on the field notes and rewatching the videos as needed for details. These themes guided our description and comparison of cases.

To examine the student notebooks, pictures of each student's notebook were taken at the end of the unit. We transcribed all student individual and team responses into a spreadsheet organize the data together. As we transcribed the student responses, we looked for themes across the notebooks. The two major points of variation we observed were completeness and variety. Completeness indicated whether or not all the students gave responses in their notebooks, and variety indicated whether or not the students gave unique responses. In order to measure the completeness of the notebooks, we counted the number of blank responses in each notebook. In order to measure the variety between the notebooks, we compared responses across the class to look for similarities and differences in the responses. Once all analysis was complete, rich case descriptions and cross-case analysis were developed based on case study methodology [22] and reported in the following sections.

Descriptions of Cases

Case 1: Mrs. J

Mrs. J teaches eighth grade science. Her classroom has two seperate areas, one with desks and one with lab tables. The students sit in their individual desks in rows for whole class and individual time and move to the lab tables to work in their teams of four. The students quickly make this transition and clearly know when they should be in teams and when they should be individually working. The students store their engineering notebooks in the classroom and take them out at the beginning of each class period. She guides her students through using the notebooks for both individual and team work and gives them explicit instructions about where to place things in their notebooks and what to write at certain times.

General Setup of Notebooks

To introduce engineering notebooks to her students, Mrs. J tells her students that the notebooks are a resource for them during the engineering design, and that they should use them "when I ask you to use it [the engineering notebook], but also when I don't ask you to use it". At the very beginning of the unit, less than three minutes after the start of class on the first day of the unit, Mrs. J has her students take out their notebooks and record the rules for the notebooks. For example, one of the rules she has them record is they should write in different colors when they are recording individual responses and team responses. Before class, Mrs. J wrote rules for what she wanted her students to put in their notebooks. To display the notebook rules to her students, Mrs. J projects the rules with the document camera and has the students copy them exactly. She follows a similar structure to introduce other times students should write in their notebooks, such as when they are copying notes about the engineering design process. When she introduces the engineering design process, she verbally tells the students to focus on the overall structure of the design process, and not worry about the details of copying it down.

Notebook Integration

When students respond to the prompts in their notebooks, Mrs. J usually has them first record their individual ideas, then work with their teams to develop team responses, and finally has a whole class discussion where she has one or two students share their team responses with the class. For example, when the students respond to the first two notebook prompts, "What do engineers do?" and "How do engineers solve problems?", she gives them three minutes of individual work time, five and a half minutes of team discussion time, and two and a half minutes of whole class discussion. In their team discussions, students rely heavily on their notebooks. To start team discussion in both of the target groups, each student took a turn reading their individual response, and the team based their discussion on the individual responses. During the whole class discussion, Mrs. J calls on two different students for each prompt to share their responses with the class, first by randomly calling on a student by drawing a name and then asking for a volunteer. When called on, the students usually read their answer directly out of their notebooks.

Mrs. J sometimes allows the students to choose if they want to record certain things in their notebooks. For example, when the students are instructed to make a list of questions for the client, she tells them that she wants their responses on a seperate sheet of paper that she will collect, but that they are welcome to also record their questions in their notebooks if they would like to and displays a template for them to do so. When students are working in their teams, she occasionally stops the students to clarify instructions and to give them time warnings.

Student Notebooks

The student notebooks from Mrs. J's class show a high level of completion and variety. For example, for the problem scoping prompts, her students left a total of only 12 blank responses for their individual responses and 1 blank team responses. Therefore, from the total of 224 each of individual responses, 5% of the responses were left blank. Additionally, 7 of the blank responses were for the question “Who are the end users?”, indicating that students disportionately struggled with a single question and likely did not understand the question. For the 12 blank individual responses, all but one of the responses was added to in the team response, indicating that the students put in effort to understand a prompt they had previously struggled with. These results demonstrate that the students had sufficient time and information to at least make an attempt at a response both individually and as a team. The responses represented a variety of responses as well. For example, for the prompt “What is the client’s problem that needs a solution?”, students’ responses included, “Need to sort minerals that spilled in the most efficient way after the train derailed”, “They need us to collect and sort different minerals that fell into a lake”, “The clients problem is their minerals are at the bottom of a lake”, and “need to sort all the rocks that fell into the lake”. Although these responses are similar, they vary enough to show that each student wrote their own response, rather than copying it from the teacher or a teammate. The responses demonstrate that each student was able to think about and record their own interpretation of the prompt using the information that they had. Additionally, these responses demonstrate that the students were considering their responses in enough depth for the teacher to assess their understanding and give useful feedback.

Some team responses differed from individual responses while others remained similar. For example, in response to the prompt, “What is the client’s problem that needs a solution?” one student wrote “the company’s minerals had fallen off the train tracks and into the water. They need them collected and sorted” for their individual response and “The train containing had fallen into a lake and now need to be sorted + collected” for their team response. This student had a pretty good understanding of the problem before the team discussion and only changed their response slightly. On the other hand, there were also students whose responses varied more. For example, a different student to the same prompt responded with “sort out the minerals” for their individual response and “a train derailed dropping all their minerals. They fell in their lake, and while they were recovered, they need to be sorted” for their team response. This student has a much more complete response after the team discussion and is able to record a more complete description of the problem.

Case 2: Mr. R

Mr. R teaches eighth grade science. His classroom is set up with rows of seats facing the front where Mr. R. stands near his desk and a smart board. At the back of the classroom are tables where students sit during group work. Mr. R communicates with his students that they are responsible for their own learning and behavior. He frequently reminds students of character expectations and rules, and discusses what he is doing and why they are performing certain class activities. On the first day, Mr. R designates teams and it takes students some time to organize into groups of three. The students store the notebooks in the classroom, and one student from each team is responsible for passing out the notebooks for the rest of the team members.

General Setup of Notebooks

As Mr. R introduces the unit and passed out notebooks, he explains their purpose for data collection in the context of the research study by clarifying that no grades will be taken. He gives his class instructions for setting up the notebooks, and Mr. R uses the notebooks for both individual and group work, depending on the task. For example, he instructs students to answer the prompts "What do engineers do?" and "How do engineers solve problems?" individually in their notebooks without discussion, while students write down questions to the client in groups and volunteer one question to the class.

Real-Life Examples

Mr. R gives his students structure to use the notebooks by discussing their real-world use by engineers, such as the use of graph paper for making diagrams. He also gives his students additional context for notebooks around the engineering design process, telling them a story about engineers who devised many solutions for a single design problem until they arrived at one that worked.

Notebook Integration

Mr. R leads a whole class discussion to answer the client questions students wrote in their notebooks. Mr. R first reads the client letter out loud to his class, then gives each group a copy of the letter to discuss. After each team writes questions for the client, they volunteer one question to share out loud while individually writing questions in notebooks and on the board. When having students answer the problem scoping prompts, Mr. R tells students to first individually write responses to each question one at a time in their notebooks. Afterwards, he has students go to their teams and discuss individual answers. When teams have had time to hear from each member, they write a team response which represents their group understanding. As students are answering prompts to identify the client and the end users in the challenge, Mr. R informs students of the differences between end users and clients to avoid misconceptions.

The student notebooks from Mr. R's classroom show high completion, with two missing sets of answers to problem scoping questions out of 27 students. The variety of responses from individuals and teams differs for each of the problem scoping questions. For example, 12 students wrote similar answers for the question "Who is the client?" 16 students answered the question "Who are the end users?" without variety. Six students gave off-topic unrelated answers to this question, suggesting that they may have been struggling to correctly identify the end users. Individually, most students defined the problem by accurately restating the disaster which had happened, and including the request for help made by the client. The notebook prompt with the greatest variety of individual responses was “Why is the problem important to solve?” Two students thought that the problem was important to the client, or because the client had requested it. Nine students referenced money or cost of the minerals as an important feature. For example, one student wrote “Because there non-renewable resourses [sic] and they might run out some day so we need to save them, And the company wants there profit.” Another said, “So the company doesn’t lose a lot of money”, and a third wrote “Because the minerals have to be reused because there is a limited supplie [sic] of them”. Five students stated broad benefits of solving the problem. Three students mentioned protecting the environment, such as wildlife in the lake. Five students stated how solving the problem would help others while citing aspects of the problem. For example, one student wrote “So people can use the mienrals [sic] and so they don’t go to waste”, while another wrote “To have minerals that are sorted so nothing bad mixes together”.

Sometimes groups in Mr. R’s class decided on answers that were different or simpler than individual answers. For example, a student's individual idea of the problem was “The problem is the minerals that tipped over on the railroad tracks and the solution is to gather them all and sort them.” After team discussion, the answer became “All the minerals are mixed up.” Sometimes a group entry enhanced or clarified important knowledge. For example, one student’s definition of the client was “The client is a company that deals with minerals being moved”, and the team response included “Someone who needs their minerals sorted”. Other times, group answers were the same for multiple members of the same team, or did not differ greatly from individual notes. For example, one student defined the end users as “The people who use the minerals to create the products for people to use”, and their team answer was “People who use the minerals for different objects.”

Case 3: Mrs. M

Mrs. M teaches a 6th grade STEM course. The teacher has the students for two periods and is responsible for both mathematics and science instruction. The students in this class have completed other engineering design-based STEM units and the teacher refers them back to other challenges they have worked on throughout the unit. The students sit at individual desks that are grouped into teams of four.

General Setup of Notebooks

To introduce the use of the engineering notebooks to her students, Mrs. M has her students open their notebooks that they previously used in a different engineering unit and has them draw a line to indicate they are starting a new unit. She then asks the students to share why they need to use notebooks and how engineers use notebooks, relying on their prior knowledge of engineering notebooks. The responses students give include that engineers use notebooks to plan, document their resources, and story their thinking. This discussion to introduce notebooks takes two minutes of class time.

Notebook Integration

When students are asked to respond to one or two prompts in their notebooks, Mrs. M tells the class the question she wants them to respond to and then writes the question one the front whiteboard as the students begin their work. The students are expected to recopy the prompt into their notebook and then respond to it. Mrs. M does not give specific instructions about how the students should display their responses. For example, when a students asks if they should write it in complete sentences, Mrs. M tells her that they can if they want or they can display their response as bullet points. Mrs. M usually gives her students both individual and team time to respond to the prompts. For example, Mrs. M introduces the first two prompts separately, giving students time to respond individually and as a team to each one. First, she gives them two minutes to individually respond to the prompt “What do engineers do?” and three minutes to talk with their teams to develop a response. Then, she gives them two minutes to individually respond to the prompt “How do engineers solve problems?” and two minutes to respond as a team. She then leads a one minute whole class discussion in which two students share their response for each of the questions. For the later sections of the notebooks that have more prompts, including the mineral exploration activity and the problem scoping prompts, Mrs. M gives the students a preprinted copy of the questions for them to write on and attach into their notebooks, instead of writing the questions on the whiteboard.

Student Notebooks

The students notebooks in Mrs. M’s class demonstrate a lack of completion in the notebooks. Initially, the responses are more complete and later become more scarce. For example, on the first two questions of the unit, “What do engineers do?” and “How do engineers solve problems?” all 21 students gave individual responses and 19 of the 21 also gave team responses. Most of these responses included a lot of information, indicating that the students had put time and thought into their responses. However, for the next structured piece recorded in their notebooks, the graphic organizer where students recorded their observations of minerals in one column and their ideas about how these observations will help them in their engineering challenge in the second column, student responses started to become less complete. Although twenty students wrote something in the first column, only 13 gave any response in the second column, and the lengths of responses varied significantly. For the final structured problem scoping piece of the notebook that we examined, the seven problem scoping prompts, although all 21 students wrote individual responses, only one students wrote team responses. However, students did respond to the earlier questions team response sections in two different colors, indicating that they understood the instructions as written on the handout. Additionally, the notebooks demonstrate many repeated answers. For example, for the second problem scoping prompt, “What is the client’s problem that needs a solution?” 17 of the 21 students wrote “minerals have fallen into a lake and need to be sorted” for their individual response. This indicates that they were recopying a response from the teacher, or from another student who volunteered an answer.

Case 4: Mrs. P

Mrs. P teaches eighth grade science. The classroom has small tables around the room with students sitting in groups, with Mrs. P’s desk and the presentation screen at the front. She has an aide who helps facilitate classroom activities. Mrs. P gives instructions to her students about focusing on the task and being respectful to others.

General Setup of Notebooks; Real-Life Examples

After introducing the unit, she tells them how engineers use notebooks to document their design process and keep notes, and check them in and out at work. She gives students instructions about how to use the notebooks, such as encouraging students to write in colors to differentiate individual and group ideas. Mrs. P tells students they are allowed to write however they wish in the engineering notebooks, compared to their more structured science notebooks.

Notebook Integration

Mrs. P instructs students to answer the questions “What do engineers do?” and “How do engineers solve problems?” individually in notebooks, then asks volunteers to share their answers. One student’s answer to the second question leads to Mrs. P’s introduction of the engineering design process as a class discussion. Mrs. P dedicates time to group work in addition to whole class instruction. For example, students take turns reading the client letter out loud to the class, then work in groups to brainstorm questions about the engineering design challenge for the client. The questions they propose in teams are recorded by Mrs. P in an online shared document. Students also read an article and take notes individually, then share them with others in their teams. Mrs. P gives students opportunity for writing in the notebooks, as well as using them for group work. For example, she first directs students to write answers to prompts about the client, the problem, the end users, criteria and constraints, and background learning in their notebooks. This is done individually with no talking. Then, she gives students time to report their answers to their teams, and together each group constructs an answer to share with the entire class. From team notebook answers, Mrs. P starts a class discussion over the problem scoping questions.

Student Notebooks

The notebooks from Mrs. P's classroom showed an average level of completion. Of the 28 student notebooks, from 19 to 22 of them were complete for five of the seven problem scoping questions. However, for the last two questions, "What will limit how you can solve the problem?" and "What do you need to learn in order to create a design?", only 11 of the notebooks contained responses. Prompts for identifying criteria and constraints had the most unrelated responses. For one student, many of the unrelated responses were guesses, and for two others they wrote that they did not know the end users or criteria. Eight notebooks either had only one of the problem scoping questions, or were missing all of them entirely.

Notebooks from Mrs. P's students had a variety of answers to most questions. For example, six students of the thirteen who wrote on-topic answers the prompt "What will make the solution effective?" said that being able to rescue the minerals was a criteria, as in a student's support for "anything that gets the minerals out of the lake". Some answers included general criteria, such as students' suggestions for "Accurate measurements", or that "Minerals have to be useable [sic]". One student had more specific criteria of "If the procedure costs less than the total value," while another felt that the solution working would be a criteria, to "make more good than harm, get done what we are being asked". Some notebooks did not have group answers, but those included were often similar to the ones written by individual students. Some group responses improved the depth or accuracy of individual answers. For example, a student answered the question "What will make the solution effective?" with "anything that gets the minerals out of the lake", and the team edited to be "anything to sort the minerals". Another student said the problem was "How to get the minerals from the water", but the team defined it as "how to get minerals from lake and how to separate them". Two groups made each team member's edits in separate ink colors, so that everyone had a unique response rather than consensus.

Cross-Case Comparison

Notebook Use

Teachers varied how much time they spent on different aspects of their instruction and how they distributed individual, team, and whole class work time. When students were brainstorming questions to ask the client, Mrs. J had her students only work in teams to discuss and record their questions, giving them 11 minutes to do so. Mrs. M, however, had her students spend time individually brainstorming questions, in their teams discussing questions, and sharing their questions with the whole class. In total, each of these pieces took 11 minutes, the same amount of time that Mrs. J's students had. Students also spent a significant amount of time writing individually in Mrs. P's and Mr. R's classrooms before talking in teams. However, in Mrs. J's class, the students were actively engaged in brainstorming and recording things for the entire 11 minutes. This could be a contributing factor to the more complete notebooks in Mrs. J's class. By letting the students have more time to work on their notebooks, it follows that the students will have more written in their notebooks. However, to gain back this time, Mrs. J's class did not have a whole class discussion and Mrs. J needed to spend the time outside of class reading the students' responses. In addition, more time spent writing individually did not improve the completeness of answers in Mrs. P's class.

Class Discussions

The teachers relied on students' written responses to varying degrees. For example, Mrs. J had her students record their questions that they wanted to ask the client and submit their written responses, and she read these written responses outside of class in order to get the information. On the other hand, Mr. R collected questions for the client on the board and kept them written at the front to revisit during the unit. Mrs. M also had her students share their questions with the whole class after their team discussion and recorded these herself. Mrs. P recorded client questions in an online document as her students volunteered their answers. This demonstrates to the students different values in what they write down. Mrs. J is showing them that they need to record their work for it to be seen, whereas Mrs. M is demonstrating that they need to say what they think in order for it to get to the client. This could be one contributing factor to why the notebooks in Mrs. J's and Mr. R's classes were more complete than in Mrs. M's and Mrs. P's. From the very beginning of the unit, Mrs. J communicated her expectation that students needed to record things in their notebooks to share with themselves, their teammates, and the client. Mr. R emphasized his expectations for students to produce high-quality work and conduct themselves responsibly. On the other hand, Mrs. M communicated the expectation that students only needed to record their responses for themselves, and not to share with others. Mrs. P did not prescribe structure or format to the notebooks compared to others they had written.

Real-Life Examples

Teachers also varied in how they provided context in real-world engineering for notebooks. For example, Mr. R told his students a story about engineers developing multiple solutions before choosing the best one. All four teachers also explained the engineering design process in detail at the beginning of the unit. They went through each step individually and often had discussions about what activity they would perform at each stage. This reinforced to students that it is an intentional, iterative procedure followed by engineers in the workplace. Mrs. P and Mrs. M also set up the notebooks by telling their students how important they are for documenting the process, referencing specific notebook characteristics such as drawing on graph paper or turning them in every day when working in industry. These examples emphasized how engineers are responsible for supervising their own work and learning through notebooks.

Individual, Group, and Class Responses

Finally, teachers varied in the extent to which they guided student responses. Most of the discussion in Mrs. P's classroom was done in small groups, rather than as a whole class. Having little guidance before answering the problem scoping prompts could be one reason why Mrs. P's students had the most incomplete notebooks. Mr. R led a class discussion while answering the client questions, but also had students spend much of the time coming up with responses alone or in groups. Mrs. J led a whole class discussion about the different components of the problem. The next day, the students responded to the prompts individually and as teams in their notebooks. This resulted in a high level of thoughtful completion and individual variety. On the other hand, Mrs. M's students all had very similar responses because Mrs. M led the whole class discussion as the students were recording in their notebooks. Students did not have the opportunity to each develop and record their own ideas before they heard the responses of their classmates. Therefore, the student responses in Mrs. J's class are much more representative of the students' thinking and provide a more valuable resource for the teacher to assess her students' understanding and give feedback.

Conclusion

From this study, we found several teaching practices that promoted better notebooking in engineering design-based STEM integration units. Engineering notebooks can capture student thinking and decisions made in their engineering designs. However, they will have greater assessment value if students are individually responding to the notebook prompts. Teachers should go beyond whole class discussion to ensure that students will later recall the important aspects identified. For notebooks to be useful for assessment and feedback, teachers must clearly communicate an expectation that students are to record their thoughts. Using the notebook prompts as a point of reflection and discussion is not sufficient to encourage students to actually write their responses down.

While activities that encourage individual reflection and team brainstorming are excellent for engaging students, the ideas from these sessions must be recorded in notebooks. Teachers should use notebooks to give feedback for students to learn in advance of testing, especially in team-based projects such as engineering design challenges. It can be very challenging to parse out what each individual team member understands and can do. By encouraging students to write their own responses in the notebook, teachers can better see how each student is learning the desired content and making informed decisions. Future research should consider how teachers can respond to student work in engineering notebooks to scaffold students forward in making informed design decisions.

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