2018 ASEE ANNUAL CONFERENCE & EXPOSITION
JUNE 24–27, 2018
SALT PALACE CONVENTION CENTER
SALT LAKE CITY, UT

Paper ID #22894

Elementary Students' Disciplinary Practices During Integrated Science and Engineering Units (Work in Progress)

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As the STEM and STEAM movements converge with the incorporation of the *Next Generation Science Standards (NGSS)* into state-level standards documents, there is deepened interest in contextualizing science learning experiences within engineering design problems [1], [2]. Research conducted even prior to the *NGSS* shows that design problems can be an effective context for the development of scientific knowledge and reasoning [3], [4], [5]. However, questions remain about how to scaffold integrated science and engineering learning experiences so that they provide all students with opportunities to develop disciplinary practices in *both* science and engineering. When students shift between inquiring into a phenomenon and designing a solution to a problem, do they need different kinds of support for documenting their work meaningfully, collaborating with peers, or working with data to support explanation and argumentation? Although curriculum developers and educators often intend for students to connect scientific findings to inform design solutions, do these connections get lost in the shuffle when a curriculum unit calls for students to transition from "doing science" (the pursuit of explanations) to "doing engineering" (the pursuit of design solutions)? Questions like these are especially important at the elementary school level, where many teachers have limited experience with science and engineering both as distinct disciplines and in integrated, interdisciplinary endeavors [6].

To begin to answer these questions, we are studying the extent to which elementary students engage in science and engineering practices during newly revised curriculum units specifically developed to integrate science and engineering learning. For this work-in-progress paper, we conducted a pilot case study of two classrooms, each led by an experienced teacher participating in a professional development initiative on connecting science curricula to engineering and problems in the local community. These two classrooms were chosen because they set up contrasting structures for student collaboration and documentation. In one classroom, students shared materials with group mates but documented their work independently via a traditional written "science notebook," which had a focus question for each day and guided instructions for data tables, sketches, and other inscriptions. In the other classroom, students worked as a team and documented their work collaboratively both on paper and with digital photos and presentations. Their paper tool was a "STEAM Challenge" packet with prompts to guide students through steps of a design process.

Theoretical Framework

The NGSS describes eight practices of science and engineering. This depiction of the disciplines is aligned with the view that one important form of learning is increasingly legitimate participation in a community of practice [7]. Emerging research on elementary students' participation in science and engineering practices suggest that teachers, researchers, and curriculum developers have many varied interpretations of the eight NGSS practices [8], [9], and these interpretations do not always align with the details provided in NGSS Appendix F [1]. We seek to build on prior research about the affordances of integrated science and engineering units by looking for evidence of selected disciplinary practices at a nuanced, fine-grained level. In this work in progress, we are investigating the following research question: *In what specific aspects* *of working with data, constructing explanations and solutions, and arguing from evidence do elementary students participate during integrated science and engineering units supported by differing collaboration and documentation structures?*

Data Collection

Participants and Curricular Context

For this study, we collaborated with two elementary teachers as they implemented newly revised curriculum units for a university-district partnership on integrating science and engineering through design challenges set in the students' local communities. Mr. K was implementing a third-grade unit targeting engineering design standards and physical science standards on forces, motion, and magnetism. The unit took place over two months with 13 sessions in Mr. K's dedicated science classroom. After previewing the overall challenge to design improved vehicles for the local public transportation agency, Mr. K guided the students through investigations of the effects of mass, propulsion system, and friction on the motion of rolling cart. In the last session of the unit, students built and briefly tested a trolley car linkage system for the design challenge. Paper-and-pencil notebooking was scaffolded with focus questions and sentence starters. After each investigation, students took time (sometimes an entire class session) to complete a notebook spread. We analyzed data from nine notebooks, consisting of, on average, 13 spreads (26 pages).

Ms. H was implementing a fifth-grade unit focused on engineering design standards and physical science standards on decomposition in ecosystems. The unit took place over three weeks with 12 sessions in Ms. H's dedicated engineering classroom. The unit began with watching videos and reading articles about how waste is handled and interviewing members of the school community about waste concerns in the cafeteria. These activities led to the design and construction of an indoor composter in a two liter soda bottle. After filling the composters, students made observations once per week for four weeks and then finally shared their results in a composter exposition. Students worked in 3 or 4 person teams throughout the unit and recorded their design process in "STEAM Challenge" packets. Though each student had their own packet, groups were encouraged to come to consensus before recording anything. All groups also took photos of their design sketches and constructions to include in a digital presentation about their design process. The five sessions on composter design and testing were analyzed for this study.[1] Data from these sessions included video/audio of two student groups (seven individual students) and their paper and digital notebooks.

Data Sources

Data sources for this study include all the written artifacts produced in each classroom (on paper or on computers), photos of design constructions, and field notes or video recordings of whole-class and small-group spoken discourse. In Classroom A, parental consent for video

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[1] The initial waste management and interview sessions were not analyzed because they were entirely focused on obtaining information, an aspect of one of the NGSS practices we elected not to study.

recording was too limited to capture video data, so we carefully observed classroom and team discourse and took field notes.

Data Analysis

To begin characterizing student participation in the eight NGSS science and engineering practices, we reviewed their definitions and inspected the entire data corpus for their demonstration. We noticed that the units did not offer students much opportunity to exhibit practices 1, 2, 3, or 5; the units featured pre-defined inquiry questions and design problems, pre-planned investigations, did not ask for model generation, and did not call for mathematizing beyond very simple linear measurement. Though Practice 8 was demonstrated in Classroom B, there was little opportunity for it in Classroom A, so it was not included in the analysis.

This review informed the decision to focus on practices 4, 6, and 7, which involve working with data, explaining phenomena, designing solutions, and engaging in argument from evidence. To analyze the student data for these three practices, we broke them down into sub-practices according to NGSS Appendix F [1] for grade band 3 to 5 (see Table 1).

For each classroom, we coded for sub-practices first with the richer data source and then triangulated with the sparser source. In Classroom A, students' writing was richer than their spoken discourse. We coded paper notebooks line by line for evidence that a student was engaging in one of the sub-practices of practice 4, 6, or 7. This was triangulated with field notes to check for additional instances of each practice carried out via oral discourse. In Classroom B, students' spoken discourse was more involved than their written records. We transcribed video footage taken during the five class sessions while students were working together to fill out their packets. Transcripts were coded line by line for evidence that students were engaging in one of the sub-practices of practice 4, 6, or 7. This was triangulated with paper packets, field notes, and digital presentations to check for any additional instances of each practice. Student packets indicated that students reached consensus during group discourse; that is, all students in a group wrote the same things in their packets.

To analyze the tabulated data, we counted the total number of instances of each sub-practice in each data set. We noted how many of the focal students in each class showed evidence of participating in each sub-practice. Per class, we put a label on the prevalence of each sub-practice in the data: demonstrated by all students, some, few, or none.

Findings

We present the results of data analysis in Table 1. Each row represents one of the sub-practices specified in the NGSS Appendix F for practices 4, 6 and 7 in grades 3 to 5. Counts indicate the number of notebook entries (Classroom A) or transcript utterances and packet entries (Classroom B) that we coded as featuring evidence of a particular sub-practice. Color indicates the proportion of the focal students in each class who made notebook entries or engaged in discourse that included evidence of the sub-practice. Sub-practice descriptions are bolded if some or all students in a class showed evidence.

Table 1. Evidence for sub-practices related to data, explanation, and argumentation.

Practice	Sub-practice	Indiv. Notebooking (Classroom A, 9 focal students)		Collective Notebooking (Classroom B, 2 focal teams)	
		Total instances	Proportion of students	Total instances	Proportion of students
Practice 4. Analyzing and interpreting data	***4.1. Represent data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships***	25	All	2	All
	4.2. Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation	19	All	4	All
	4.3. Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings	0	0	0	0
	4.4. Analyze data to refine a problem statement or the design of a proposed object, tool, or process	0	0	0	0
	4.5. Use data to evaluate and refine design solutions	2	Few	0	0
Practice 6. Constructing explanations and designing solutions	***6.1. Construct an explanation of observed relationships***	29	All	1	Some
	6.2. Use evidence (e.g., observations) to construct or support an explanation or design a solution	21	All	0	0
	6.3. Identify the evidence that supports particular points in an explanation	15	Some	0	0
	6.4. Apply scientific ideas to solve design problems	11	Some	7	All
	6.5. Generate and compare multiple solutions based on how well they meet criteria and constraints	0	0	1	Some
Practice 7. Engaging in argument from evidence	*7.1. Compare and refine arguments based on an evaluation of the evidence presented*	0	0	0	0
	7.2. Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation	0	0	0	0
	7.3. Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing specific questions	0	0	0	0
	7.4. Construct and/or support an argument with evidence, data, and/or a model	3	Few	9	All
	7.5. Use data to evaluate claims about cause and effect	0	0	0	0
	7.6. Make a claim about the merit of a solution by citing relevant evidence about how it meets criteria and constraints	12	All	7	All

We note at least three key findings. First, in both classrooms, there was strong evidence of at least one sub-practice from each larger practice: representing data in graphical displays and interpreting data within Practice 4, explaining observed relationships within Practice 6, and citing evidence when making a claim about a design solution within Practice 7. This means that science and engineering units contextualized by community design challenges *can* be sites for elementary students' disciplinary practice. Second, there was no evidence in either class of three sub-practices related to working with data and four sub-practices related to argumentation. This means that components of each larger practice are distinct enough that a curriculum or learning support may foster one without the others. Third, the two classrooms differed in which sub-practices they better supported. Classroom A, with individual notebooking and daily focus questions, had several instances per student of using evidence to construct an *explanation* (6.2), while Classroom B, with collective documentation, had zero instances. By contrast, Classroom B had many instances of constructing or supporting an *argument* with evidence (7.4), while Classroom A only had a few instances. This contrast confirms that *explaining* how or why something works is a different task for students than *arguing* to justify an idea, and different curricula and classroom structures may generate the need for one task but not the other.

Discussion and Implications

The eight summary definitions of the NGSS practices are often the only information teachers have to judge student participation in disciplinary practices. If we had simply coded by these definitions, we might have mistakenly concluded that students were participating fully in practices 4, 6, and 7. Instead, when we used Appendix F of the NGSS to break those practices down into sub-practices, a more complex and nuanced picture of student participation emerged.

When we analyze at the sub-practice level, we can see that there are other opportunities related to data, explanation, and argumentation that need to be provided for these students. For example, in these two curriculum enactments we did not find the use of data to refine design solutions (4.5) or to evaluate claims of cause and effect (7.5) even though students did represent and interpret data (4.1, 4.2). This result may have occurred because the units did not allocate adequate time for testing and iterating on design solutions, or because they did not privilege sense-making about why design solutions performed the way they did.

The findings also suggest that teacher choices about how to structure engineering design processes may make a difference in which sub-practices are available for uptake by students. In Classroom B, Ms. H encouraged students to reach consensus during each step of their design process. This collective structure may have created a need to justify design proposals with science ideas (6.4). The nature of design *planning* in each class may also have influenced opportunities to engage in sub-practices that connected science ideas or data to design processes: Ms. H requested a collective design plan before students could build; Mr. K did not.

These pilot study findings have implications for the design of integrated science and engineering curricula at the elementary school level. However, the generalizability of the findings is limited by the difference in data sources between the two classrooms and the preliminary nature of our analyses. We plan to continue working with these teachers and their colleagues to investigate how different curriculum choices and instructional scaffolds influence students' participation in specific elements of science and engineering practices. Next steps include collecting both video data and student documentation artifacts from more classrooms and conducting a similar analysis with additional steps to establish the trustworthiness of our coding methods.

Acknowledgements

Special thanks to our collaborating teachers and their students for their participation in this study. This material is based upon work supported by the National Science Foundation under Grant No. 1657218. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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