2018 ASEE Annual Conference & Exposition
June 24-27, 2018
Salt Palace Convention Center
Salt Lake City, UT
Paper ID #23386

A Teacher's Use of Engineering Language in an Engineering Design-based STEM Integration Unit (Fundamental)

Emilie A. Siverling, Purdue University, West Lafayette

Emilie A. Siverling is a Ph.D. Candidate in Engineering Education at Purdue University. She received a B.S. in Materials Science and Engineering from the University of Wisconsin-Madison and an M.S.Ed. in Science Education from Purdue University, and she is a former high school chemistry and physics teacher. Her research interests are in K-12 STEM integration, primarily using engineering design to support secondary science curricula and instruction.

Prof. Tamara J. Moore, Purdue University, West Lafayette

Tamara J. Moore, Ph.D., is an Associate Professor in the School of Engineering Education and Director of STEM Integration in the INSPIRE Institute at Purdue University. Dr. Moore's research is centered on the integration of STEM concepts in K-12 and postsecondary classrooms in order to help students make connections among the STEM disciplines and achieve deep understanding. Her work focuses on defining STEM integration and investigating its power for student learning. Tamara Moore received an NSF Early CAREER award in 2010 and a Presidential Early Career Award for Scientists and Engineers (PECASE) in 2012.

Siddika Selcen Guzey, Purdue University, West Lafayette

Dr. Guzey is an assistant professor of science education at Purdue University. Her research and teaching focus on integrated STEM Education.

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Introduction

Engineering practices and concepts are increasingly expected to be taught in pre-college classrooms, as is evident in state [1] and national [2] science standards. One of these practices is the ability to communicate engineering effectively, which includes understanding and using engineering design language. *A Framework for K-12 Science Education*, the document upon which the national science standards were based, includes obtaining, evaluating, and communicating information as one of the eight science and engineering practices [3]. Another comprehensive report relating to pre-college engineering education, *Engineering in K-12 Education*, lists communication of one of the six key engineering "habits of mind" [4]. Authors [5] also support communication as an important facet of pre-college engineering education. Of the nine indicators in the *Framework for Quality K-12 Engineering Education*, communication related to engineering was found to be one of the five indicators essential to adequate quality of an engineering education curriculum, partially because it is needed to help students develop their understanding of engineering. Communication in engineering requires students to be able to understand multiple representations (e.g., verbal, written, symbolic) and also understand technical and everyday language related to engineering [3], [5].

Atman, Kilgore, and McKenna [6] studied how undergraduate engineering students' knowledge and use of engineering design language changed over time and how it influenced their design practices. They found that over the course of their undergraduate experience, their language become more engineering-specific. Additionally, this increase in design-related language was accompanied by a shift in how students approached solving a design problem; this shift was toward, though not fully at, approaches used by expert engineers. This study suggests that understanding engineering language influences student learning of engineering.

Engineering language is also important to pre-college STEM integration. The NAE and NRC report [7] *STEM Integration in K-12 Education* listed several implication for STEM integration, the first of which is that "integration should be made explicit" (p. 5). As such, in integrated STEM curricula, it is important that engineering language be used not only during the lessons in which engineering content and practices are the focus, but also in the science- and mathematics-focused lessons.

These sources show that communication, especially engineering language, is an important part of pre-college engineering education and STEM integration. While the ultimate goal is for students to learn and understand engineering language, the first step in using engineering language in the classroom is through teachers' use of engineering terminology. Therefore, this study explores how a teacher used engineering language during the science- and mathematics-focused lessons of an engineering design-based STEM integration curricular unit. Specifically, this purpose of exploring how a teacher uses engineering language is represented two research questions: *a) What engineering language does a teacher use during science- and mathematics-focused lessons?, and b) When in each lesson and in what contexts is engineering language used?*

Theoretical framework

In Vygotsky's sociocultural theory of learning, the principle belief is that one's internal consciousness is generated from outside social contact with others [8]. Psychological tools like language and gestures not only help a person interact with others, but they are also key to developing higher mental functions (e.g., decision making) from lower mental functions (e.g., perception, memory). Additionally, Vygotsky defines two types of concept formations: scientific and spontaneous. Scientific concepts are highly defined and coherent, having been refined over time by a society or community. Spontaneous, or everyday, concepts are those that arise from one's own experiences. In her three-part Vygotskian theoretical framework, Goos [9] described this interpretation of Vygotsky's zone of proximal development by writing, "Mature knowledge is achieved with the merging of everyday and scientific concepts – not by replacing the former with the later…but by interweaving the two conceptual forms" (p. 265).

Teachers are often the representatives of the engineering community in pre-college classrooms, and thus it is their responsibility to facilitate links between students' everyday spontaneous concepts and language about engineering with the "official" language and concepts of the greater engineering community. This study does not address students' spontaneous concepts and language related to engineering, instead focusing on the engineering language that a teacher uses. Specifically, we aim to explore the spontaneous and scientific design language that a teacher uses during the science- and mathematics-focused lessons of an engineering design-based STEM integration curricular unit.

Study design

Participant and curriculum background

The participant in this study was a 7th grade life science teacher. She had attended a three-week teacher professional development during the summer prior to this study. The first two weeks of the professional development focused on content and pedagogies related to engineering, data analysis and measurement, and the life science subject of ecology. During these weeks, the teachers participating in the professional development completed two middle school level, engineering design-based STEM integration curricular units and also learned about STEM integration. Throughout this process, the teachers were exposed to a variety of engineering design language via the curricula and the professional development facilitators. The third week focused on curriculum writing, during which time teachers formed curriculum writing teams and developed an integrated STEM unit that included an engineering design challenge and standards-based science and mathematics content. Parts of the curricula were implemented with student volunteers in a summer school program, and the teacher teams revised the curricula based on that pilot experience. These second draft curricula were implemented in the teachers' classrooms.

The teacher who was the focus of this study was in a team with two other 7th grade life science teachers. They developed a curriculum called *Loon Nesting Platforms* that integrated science concepts related to ecology, mathematics concepts related to area and data analysis, and an engineering desing challenge. The engineering design challenge presented to the students had two main parts to it: design, create, and test a floating platform that loons could build a nest on, and choose the best lake to test the platform on. The seven lessons of this unit took 13 one-hour class periods to implement. Table 1 shows the focus of each lesson and the length of time of implementation.

Table 1
Loon Nesting Platforms Curriculum Overview

Lesson	Class Time	Topics Covered
1	1 hour	human impact on the environment, introduce engineering challenge
2	1 hour	loon traits and ecosystem needs, ecosystem vocabulary
3	3 hours	food chains and food webs, create loon food web
4	1 hour	determine which local lake is most suitable for platform
5	1 hour	calculate the area of the platform prototype, create template
6[a]	4 hours	design, create, and test platform prototype
7[a]	2 hours	redesign, re-create, re-test platform prototype

[a]These two lessons were the design/create/test (i.e., the engineering-focused) lessons of the curriculum. Because of the focus of the research question, these lessons were not analyzed in this study.

Data sources

The data for this study were seven hours of classroom video during which time the teacher implemented the first five lessons of the unit. The main focus of these five lessons was either science or mathematics content. These lessons were chosen since the purpose of this research was to examine how engineering language was used in science- and mathematics-focused lessons during an engineering design-based STEM integration unit. The portions of the lessons that contained the teacher using engineering language or implied engineering language when addressing the whole class were transcribed, as well as gestures relating to engineering (e.g., pointing at a step in the design process displayed on the front wall). Curricular materials, including lessons plans, teacher powerpoint slides, and student worksheets, were used as supporting material to help better understand the context of the video data.

Analytical framework

In order to identify scientific engineering language, those terms that have been developed and refined by the engineering community, we used engineering terms from three sources related to pre-college engineering education. The first source, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* [4], contained italicized engineering terms in the second chapter, What is Engineering? We cross-referenced these terms with those used in the Scientific and Engineering Practices portion of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [3]. The terms found in this source were those that were used in the description of engineering practices but not scientific practices. Finally, we added terms from the design cycle that the teacher had chosen to use in the classroom [10]. Table 2 shows the engineering terminology found in each of these sources.

Although all of the engineering design terms in Table 2 had been used during the professional development experience, different terms received a different amount of emphasis. Thus, the purpose of using these terms as the analytical framework of the study was not to see how well the teacher picked up on every single engineering term used during the professional development. Rather, we assembled this analytical framework in order to set bounds about what would typically be considered appropriate engineering terminology for pre-college teachers and students.

Table 2
Engineering Language and Terminology in Pre-College Engineering Education

Source	[4][a]	[3][b]	[10][c]
Terms	Engineering	Engineering	Problem
	Design	Design	Explore
	Specifications	Criteria	Design
	Constraints	Constraints	Create
	Optimization	Optimal	Test (Try it out)
	Systems	(Engineering) Problem	Redesign (Make it better)
	Modeling	Prototype	
	Trade-offs	Trade-offs	

[a]*Engineering in K-12 Education: Understanding the Status and Improving the Prospects* (pp. 38-43). [b]*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (pp. 50-53). [c]*Engineering Design Process* from theworks.org.

Data analysis methods

In order to answer the research questions, we used thematic analysis of the video transcripts, which is also known as semantic content analysis [11]. Our backgrounds in engineering and education provided us with the needed familiarity of the subject matter content that is required to do an appropriate thematic analysis. This allowed us to "see that the same concept or relationship can be expressed by many different verbal forms and grammatical constructions, and to exclude cases for which the form is right but the meaning in context is not" [11, pp. 1476]. For example, the term "problem" appeared more times in the transcript than it was actually coded as engineering language, since we were able to distinguish between "problem" used in an engineering context from "problem" used in a different context. We coded the transcripts in two phases. During the first phase, we used deductive analysis to identify the scientific engineering language from the analytical framework shown in Table 2. This was followed by a second phase, during which we used inductive analysis to search for implied or spontaneous engineering language, such as synonyms and phases that relate to engineering language but were not explicitly the terms in Table 2. We addressed the first research question by coding which terms were used, as well as their frequency. In order to answer the second question, we also coded the context and part of the lesson in which each of the terms was used.

Findings

What engineering language does a teacher use?

Table 3 shows the frequency count of the engineering language used in the first five, science- and mathematics-focused lessons of the *Loon Nesting Platforms* curricular unit.

Table 3

Frequency Count of Engineering Language Used in Science- and Mathematics-Focused Lessons

Term	Frequency: Verbal	Frequency: Gestures[a]
build/building[b]	17	-
design/designing	10	2
(engineering) problem	9	1
explore/exploring	8	3
plan/planning[b]	5	-
(engineering) design cycle/process[c]	4	1
engineers/engineering	4	-
prototype	2	-
model	1	2
create/creating	1	1
requirements[b,d]	1	-

[a]This column indicates instances in which the teacher gestured to either the entire engineering design cycle or a specific step within it. [b]These terms were those used by the teacher that were not in the engineering language analytical framework; rather, they were used as synonyms for other engineering language terms. [c]The frequency counts for (engineering) design cycle/process do not overlap with the frequency counts of design/designing and engineers/engineering. [d]"Requirements" was included here because it was used in a context in which the teacher was essentially referring to "specifications" or "constraints," both terms in the analytical framework.

While the teacher used many engineering terms from Table 2, the most frequent term used was "build" or "building." One of the aspects of the engineering design challenge presented to students was the construction of a prototype platform, and this is the aspect that the teacher emphasized most to the students. The teacher also frequently referenced early parts of the engineering design cycle (i.e., problem, design, explore, create). The later steps (i.e., test, redesign) were not said or implied at any point during the first five, science- and mathematics-focused lessons. An interesting note about one of these terms is that "plan" or "planning" was only used in lesson 5. In the four lessons prior, the teacher used the term "design" or "designing," but she substituted "planning" for "designing" in lesson 5. For example, she stated, "We're going to really start planning our platform" during this lesson.

When in the lesson is the engineering language used and in what context?

Other than lesson 5, the teacher used engineering language exclusively at the beginning or end of the science- and mathematics-focused lessons. In the first lesson, engineering language was used in the final 10 minutes of the lesson as the teacher introduced the engineering problem and the design cycle that the students would be using. After most of the first lesson focused on human impacts on the environment generally, the teacher explained to the students how humans' shoreline development has reduced places for loons to build nests. The teacher then briefly introduced the idea of the loon platform and began to use engineering language, stating, "So your task in the next couple of weeks, is we are going to be engineers, and we are going to design a platform." This was followed by an overview of the design cycle, during which time many engineering language words and gestures were used. This excerpt demonstrates the teacher's explanation of the design cycle:

> "So today we're talking about this is our problem *[points to problem area of design cycle].* So when you guys come back on Monday, we're gonna start to go on to exploring *[points to explore area of design cycle].* And what we have to explore is, we have to explore…we need to understand a little bit more about loons... So in order to give them a good nesting platform, we have to understand some things about them**.** Ok? Make sense to everybody? So that's where we're going to go into exploring *[gestures to explore area of design cycle]* and then we'll explore some options and we will start to design a platform *[gestures to design area of design cycle]*. So in a week or so, we will be designing and actively building a platform for, for the loons, a prototype platform."

This example also demonstrates the most common use of engineering language in the science- and mathematics-focused lessons, which was as a timeline reference. The teacher frequently used engineering language to tell the class where they currently were in the design process and where they were going; this type of use of engineering language occurred at the beginning of the lesson (lessons 2, 4, and 5) and/or at the end (lessons 1, 3, 4, and 5).

Engineering language was used in two other ways during lesson 5. At one point, the teacher gave the students an example of "engineering gone wrong" from her past experience working with loons as a research assistant. She and her colleagues had designed and created a model of an adult loon upon which orphaned loon chicks could sit to stay out of the water. They had purposefully made the ramp up to the model loon's back somewhat rough so that the loon chicks would have traction, but unfortunately it was too rough for the chicks' feet and it hurt them. In addition to this story, the teacher also used engineering language to explicitly tie the mathematics content the students were learning in lesson 5 to the engineering problem by stating, "You guys are going to do, like, a prototype, scaled down from a real size." While the teacher had used references to the engineering design cycle to tie the students' science and mathematics learning to the engineering challenge generally, this connection to mathematics was directly tied to one of their engineering tasks.

Missed opportunities

In addition to noting where engineering language was used in the lessons, it was also interesting to note where engineering language was not used but could have been. One example is the frequent use of the terms "build" and "building" instead of more official terms like "design," "create," or "implement." The students were indeed going to be building a prototype platform, so it was not technically incorrect to use that term. However, if the teacher had used terms and gestures that directly linked back to the engineering design process that was posted at the front of the room, it may have been easier for students to see the connection between the science- and mathematics-focused lessons and the engineering process. Additionally, while the teacher often made references to the beginning stages of the design process, she did not use any language related to the testing and redesign portions of the design cycle during the first five lessons.

Another important instance of missed opportunities for the use of engineering language was the entirety of lesson 4. The purpose of lesson 4 was for students to choose the local lake on which they were going to test their platform, which was one of the tasks given to them by their client. In order to choose the best lake, students had to analyze four different types of data about six lakes; each of these four data types was a factor that would be important to loons. The students first had to rank the four factors in terms of what they thought would be most important in their decision, and then they had to rank the six lakes to determine the "best" one. When writing the curricular unit, the teachers had categorized this lesson as science- and mathematics-focused because of the heavy emphasis on loon ecology and data analysis. However, this task also required students to do engineering-like thinking, since they were dealing with trade-offs and considering a somewhat open-ended problem. However, the teacher did not use any engineering language during this activity. She did say that there might be multiple possible solutions, though she did not use those terms, by stating, "We're gonna rank our lakes and choice – and again, we're not all going to necessarily agree on this." Additionally, when reviewing lesson 4 at the beginning of lesson 5, she said, "…there were probably four pretty good [lake] choices…[and] a couple that weren't maybe the greatest." This idea that there is not necessarily one best solution, but there may be more or less ideal solutions, is a key idea in engineering. However, the teacher did not link this concept back to engineering using engineering language.

Discussion and implications

First, the teacher in this study provides an example of what and how engineering language can be incorporated into science- and mathematics-focused lessons in an engineering design-based STEM integration unit. The most frequent way used by this teacher was to place each lesson in the context of the engineering design process; this process of framing the lesson with the engineering challenge usually occurred during the first and/or last few minutes of each lesson. This study could provide a helpful example for teacher professional development leaders to use to show how engineering language can be used to remind students about the unit's engineering context without taking a lot of time away from the main lesson focus of science or mathematics content.

A second implication of this study is the need for professional development leaders and teachers to be more explicit and purposeful with their engineering language. As discussed above in the theoretical framework, Vygotsky's zone of proximal development can be described as the interweaving of a learner's spontaneous/everyday concepts with a wider community's established, ordered scientific concepts [8]. Many teachers will enter professional development opportunities similar to how most students will enter a classroom – with many spontaneous concepts and language related to engineering. In order for these teachers and students to learn about engineering, the concepts and language of the engineering community need to be used explicitly by instructors. Teachers will not only need to learn engineering language to help develop their own understandings about engineering, but they also need to be aware of recognizing students' everyday language related to engineering and relating that to the language of the engineering community. For example, instead of focusing on the spontaneous concept of "engineering as building," as was evident in this study, teachers could instead emphasize the more official view of "engineering as designing" [4], [5].

Limitations and future work

This study had several limitations. First, we only evaluated one teacher during one of her class periods. If we had video data of other class periods, we could have seen what language the teacher used throughout the day, or we could have analyzed video data from the other two teachers who helped create the unit to see what kinds of engineering language they used. Additionally, this study only represents the implementation of one middle school level, life science STEM integration curricula. Other grade levels or science disciplines (e.g., physical science, earth science) may be more or less conducive to using engineering language during science- and mathematics-focused lessons. Because this study is an in-depth focus of one teacher's use of engineering language, future research on other teachers, subjects, and grade levels would be required in order for it to be more generalizable. Finally, we did not analyze any student data, including their audio or written artifacts. Future work could include comparing student use of scientific and spontaneous engineering terminology throughout an engineering design-based unit with that of the teacher in order to ultimately determine how a teacher's use of engineering terminology affects student conceptions about engineering.

Acknowledgements

This work is supported by the National Science Foundation under grant number NSF DRL-1238140. Any opinions, findings, and conclusions or recommendations conveyed in this study are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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