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Teacher Engineering Talk About Problem Scoping in a Middle School Engineering Design-based STEM Integration Unit (Fundamental)

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Introduction

There is growing interest in considering the integration of science, technology, engineering, and mathematics (STEM). Many researchers agree that curriculum integration provides opportunities for students to learn a variety of discipline areas in real-world situations [1]–[3]. Engineering has a vital role to integrate STEM components effectively because engineering provides many opportunities for students including a real-world context for learning mathematics and science, and engineering design task for improving high-level thinking and problem-solving skills [3]. To prepare students with these skills, it is necessary to provide the variety of ways to teach STEM integration. This study aims to investigate how an effective teacher with middle school age students talks about problem scoping in an engineering design-based STEM integration unit to help teachers and educators understand how to use engineering talk. The research question that will guide this study are as follows: How does a middle school life science teacher use problem scoping during an engineering-based STEM integration unit?

Background

In the last two decades, the need for integration STEM disciplines has become apparent in precollege education. To prepare students with strong STEM backgrounds, it is necessary to provide advantageous for students to learn meaningful scientific concepts through rich, engaging, and powerful experiences [3], [4]. Recent studies and report demonstrated that integration of STEM components is important to solve engineering problems [4]–[6]. Even though researchers and educators give an importance for integrations STEM disciplines, there is not much guidelines or models for teachers to implement STEM integration into their classroom.

Engineering design has a vital role in pre-college student's STEM education preparation. Studies indicated that teaching engineering design in meaningful contexts provide many opportunities for students including student learning and success in mathematics and science, and increase students’ motivation in STEM areas [7], [8]. While many studies support to incorporate engineering design into K-12 curricula, there are some challenges that teachers have for this integration. Teachers lacked the knowledge and experiences to teach engineering design challenges [8], [9]. Therefore, pedagogical knowledge in engineering is an essential component for integration of engineering design into classroom meaningfully. The studies described above and others suggested that there needs to be more research about the pedagogies to make this integration purposefully.

Framework

We used a theoretical framework based on The Framework for Quality K-12 Engineering Education [10]. This framework includes nine indicators of quality K-12 engineering education that include the complete process of design, problem and background, plan and implement, test and evaluate, apply science, engineering, and mathematics, engineering thinking, conceptions of engineers and engineering, engineering tools, issues, solutions, and impacts, ethics, teamwork, and communication related to engineering. Although these are all essential factors for a holistic engineering education, for this study, we focus on one aspect, problem and background, to analyze how the teacher uses problem scoping engineering talk.

Problem scoping and understanding the problem is a major task for engineering designers because engineers are "rarely… given a specific, well-defined problem to solve" [8, pp. 12]. In design, "problem setting is as important as problem solving" [9, pp. 281] and is so intertwined with solution generation that they cannot be separated [13]. In design, the designer's definition of the problem changes throughout the design process because "problem spaces and solution spaces co-evolve" [11, pp. 363] and the problem is not fully understood until the solution is developed because "an engineering goal has a way of changing throughout a design" [8, pp. 12]. Therefore, designers must delay their decision making until they have considered many aspects of the problem and better framed the problem [7]. A better understanding of the problem and a better analysis of the client's needs is "positively related to client satisfaction" [15]. Additionally, problem framing and representation can help designers to make the creative leap from problem to solution and to represent the problem in a way that makes the solution more clear [16]–[18].

To begin to understand the problem and develop the solution to that problems, designers must engage in rigorous problem scoping, including "identifying criteria, constraints, and requirements; framing the problem goals or essential issues; gathering information; and, stating assumptions about information gathered" [11, pp. 361]. Designers must "learn through research, brainstorming, and doing technological investigations what the critical issues are in order to frame the problem effectively" [5, pp. 747]. Designers must work to not only understand the problem as stated by the client or user, but also the many aspects of the problem and its environment that affect the solution. Without thorough problem scoping, a designer cannot fully understand the problem they are trying to solve, let alone develop an appropriate solution to that problem. In addition to being ill-structured and having multiple solution paths, the complexity of design problems require engineers to look at the entire system of the problem [13], [19]. Therefore, the information they learn and develop in problem scoping must be as broad as they deem reasonable given the other constraints of the problem. Additionally, they must identify doable pieces of the problem and evaluate how these pieces effect the whole [18].

Problem scoping is a skill that designers need to learn and practice to be effective. Novice designers often do not realize the importance of problem scoping before jumping into solution generation because “novices often do not realize that they do not understand the problem or feel that they understand the problem well enough” [11, pp. 361]. Therefore, they do not spend the time needed to examine the problem and to do the background research to learn about the many aspects of the problem, driven by questions the designer asks about the problem about many dimensions of the problem [7], [20], [21]. Young students have demonstrated abilities in problem scoping complex problems, including evaluating the user needs, criteria, and constraints of the problem, even if they do not have the language to describe their processes or a systematic method [22], [23]. Also, their abilities are inconsistent and vary between problems and contexts. As students progress through the design process, they can become overwhelmed with the many complexities of developing their solution and refer less often to problem scoping [24]. . Engineers’ problem scoping abilities become more refined with experience. For example, expert designers spend a significant amount of their time on problem scoping and seek out diverse information related to the problem [14], [25], [26]. These strategies allow the expert designers to more fully understand the landscape of the problem as they work through their solution generation.

Research question

The purpose of this research is to examine how a middle school science teacher uses engineering talk to support his students’ problem scoping. To do this, we address the research question: How does a middle school life science teacher use problem scoping engineering talk during an engineering design-based STEM integration unit?

Methods

We used a case study approach in order to deeply analyze the engineering talk of a teacher [27]. We conducted this study in Mr. Evans’ sixth grade life science class in a midwestern middle school. Table 1 displays the demographics of the school.

Table 1. School Demographics

Variable	Percentage of Student Population
Race/ethnicity	
White, non-hispanic	*73*
Black, non-hispanic	*9*
Hispanic	*6*
Asian	*12*
Special Ed.	*10*
ELL	*3*
Free/reduced lunch	*9*

At the time of this study, Mr. Evans had eight years of teaching experience in science. Mr. Evans chose to participate in a three-year professional development (PD) and implementation program prior to this study. During the summer PD, that was conducted by the authors, Mr. Evans worked with a team of two other teachers to develop a curriculum unit to integrate engineering into their life science classes. The teachers then implemented the unit into their classes. During these implementations, Mr. Evans stood out as an effective teacher whose students performed well on science posttests [28]. Additionally, Mr. Evans demonstrated use of many engineering and pedagogical practices that supported student learning , especially in his teacher talk, such as in how he posed questions and elaborated on student responses [29]. The purpose of this study is to further examine how he demonstrated engineering practices in his teacher talk, especially in terms of how he used his talk to support students' problem scoping.

The life science based engineering design unit was implemented over the course of 18 fifty minute class periods. The students were given the problem that non-GMO farmers and GMO farmers needed to keep their fields separated from pollination. The students were given this challenge in the form of a letter from the client. During the unit, the students learned background information about the engineering design process and life science concepts to support their work on the engineering problem. Table 2 provides a brief overview of the topics for each class period. The unit covers NGSS main ideas: MS-ETS1: Engineering Design, MS-LS3: Heredity: Inheritance and Variation of Traits, and crosscutting concepts: cause and effect and structure and function. Additionally, the unit addresses eight science and engineering practices recommended in NGSS including defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information.

Table 2

Lesson	Day(s)	Focus of Whole Class Discussions
1. Introduction of Engineering Challenge	1	What is engineering?; Introduction to the engineering challenge with the client letter
	2, 3	Basics of GMOs; Debate for or against regulation of GMO crops
2. Introduction to DNA Structure and Function	4, 5, 6, 7	Structure of DNA and chromosomes using a balloon model and an origami model; DNA extraction lab
3. Genes and Trait Expressions	8	Traits of family members; Dominant and recessive genes and traits

4. Introduction of Heredity	9, 10	Sexual and asexual reproduction; Mitosis and meiosis; Relationships between these ideas
5. Applied Heredity	11	How to use Punnett squares to study heredity
6. Genetic Modification	12	Genetic modification using plasmids; Students construct a paper model of a plasmid
7. Scale Model Research	13, 14	Reasons to use scale models; How to perform scale model calculations
8. Engineering Challenge	15, 16	How to plan and build solution to the engineering challenge
	17, 18	Solution testing procedures; Prepare to present solution idea to the client

All eighteen lessons were video recorded and transcribed. This analysis focused on teacher talk during whole class discussions, rather than individual or small group work time, in order to analyze how the teacher presented problem scoping to all of the students. The transcripts were coded based on different components of problem scoping. The codes and an example of each code are listed in Table 3. In addition to the instances of problem scoping, other talk related to engineering was also coded as engineering talk. Teacher talk not related to engineering, such as instructions or procedures, was not included in any coding.

Table 3

Code	Example
General Problem and Background	“This is the last final step in understanding this process. How does the actual GMO get made? Your job, for our clients, is not to stop GMOs from being made. We're not going in trying to interrupt this process. Our job is to help non-GMO farmers keep their plants isolated or avoid fertilization from a GMO plant. It's good to understand the process as well” (Day 12).
Criteria	Mr. Evans: Let's clarify what is it that the client wants. Raise your hand if you can tell me one thing that client wants, okay. [Student 1]? Student 1: A functional solution to cross pollination of GMO to non GMO. Mr. Evans: Solution to cross pollination of non GMO's by GMO product. That's actually a good summary. Anyone else want to add anything about what they want? Student 2:Should be inexpensive.

	Mr. Evans: Good. Inexpensive. Student 3: Easy. Student 4: Effective. Student 5: Functional. Easy to implement (Day 1)
Constraints	Mr. Evans: "Keep in mind, and I'm sure this is sort of common sense to you, but you obviously want to realize that the farmers need their crops. I could easily solve their problem by going and killing all their crops and then I'll say, look, no more cross pollination. Right, but then, that doesn't make sense because then they don't have their crops. You've got to work within the constraints that our client is working. I think it's a fair assumption to make that they want all of their corn crops to grow but they want to prevent cross pollination" (Day 15).
Client	Mr. Evans: "What I want you to do to start with is brainstorm with the group. Sketch some ideas. Think about how it might impact the crops. Think about the needs of our client. When your group is confident that you think you have a pretty good design you can bring that forward and I will check it out"

The transcripts were coded to consensus by two authors, consulting the other authors as needed to resolve disagreements. To analyze the coded transcripts, we looked across lessons to analyze the variety of examples of problem scoping talk and how this was used in each context. Additionally, we made process flow charts to analyze the order and flow of each of the elements of the teacher talk. These flow charts were made based on how long Mr. Evans talked about each aspects of problem scoping relative to how he talked about engineering as a whole. We compared the flow charts across lessons and as a whole to examine patterns and themes in the teacher talk.

Results

Mr. Evans included problem scoping in a variety of ways throughout his teaching. This section discusses how he integrated problem scoping along with examples of what he said.

Mr. Evans used problem scoping engineering talk throughout the unit. Figure 1 which displays the amount of time (represented by lines of transcript) that Mr. Evans' talk focused on the problem or its components. In almost every lesson in the unit, Mr. Evans talked about problem scoping, although the length of his talk varied. On days 17 and 18, students had completed the engineering design challenge and were primarily focused on reviewing for and completing a summative assessment, therefore, Mr. Evans had only a small amount of engineering talk, and none that was focused on problem scoping. Throughout the process, as students were introduced to the problem, learned background science knowledge, and worked through the later stages of the engineering design process, Mr. Evans talked about problem scoping.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
General Problem/Background (POD-PB)	76		16	3	29	8		14	17	9	7	17	15	5	3			
Client	3				3			2							6	2		
Constraints	9														9	6		
Criteria	17														7	20		
Total Engineering Talk	198	43	323	271	81	155	23	349	343	154	341	205	62	190	90	94	13	17

Figure 1. Teacher talk time spend on each aspects of problem scoping throughout the unit. Numbers represent number of lines of transcript of Mr. Evans' teacher talk.

The most common way Mr. Evans talked about problem scoping in the unit was by talking about the problem and the client’s needs generally as a way to remind the students why they were learning the science they were learning. For example, on day 5, Mr. Evans told his class:

> So as we start thinking about our client's concern, our client's desire to help prevent cross-contamination, cross-pollination of GMO and non-GMO plants, we need to start forming a good understand of just exactly how that happens.

On day 10, Mr. Evans told his class:

> Remember the focus is what's going on with the DNA, and that's the biggest focus on what is the different sexual and asexual reproduction. DNA's the focus because we know that GMOs are determined by DNA, and so once we understand the reproductive strategies, that can help us understand our client's concern with the word cross-pollination which as we know sexual reproduction strategy.

In these examples, Mr. Evans reminds his students of the engineering challenge and the client that is relying on them to develop a solution as a way to explain to his students why they are learning the science behind GMOs. He reminds the students about the client and generally tells them how their scientific understanding will help them solve the client’s problem. By doing this, Mr. Evans modeled for his students how the problem gets more defined as they work through the design process and Mr. Evans helped the students define and redefine the problem throughout the unit.

In addition to talking generally about the problem throughout the unit, at the beginning and end of the unit, Mr. Evans focused more specifically on the criteria and constraints of the problem. For example, on day 15, Mr. Evans, as the students are working on their plan for their solution, Mr. Evans had the following dialogue with his students:

> Mr. Evans: Who can remind me what our client wants? [Student 1]?
>
> Student 6: Cheap, easy, and it has to work.
>
> Mr. Evans: Good. [Student 2], what else?
>
> Student 7: It has to be inexpensive, easy to make, and then efficient.
>
> Mr. Evans: Efficient, yeah, good. Anything else that we know? [Student 3]?
>
> Student 8: But it would take a long time like build a brick wall or something?
>
> Mr. Evans: Right. We have some conditions in those conditions where you should have in the early pages of your engineers notebook. When you and your group decide what you want and what you're going to design you should certainly consider all of those client requests but realize also that rarely does something meet one-hundred percent of the client's needs. Especially the first time around. Remember the big issue becomes can you sell your product to the client and convince them that yours is better than anyone else's. Even if yours maybe is a brick wall that's timely and maybe not the easiest to put up, can you convince them with other aspects of it that might make it worthwhile to them.

In this example, Mr. Evans asked the students to share their understanding of the problem. He asked for specific pieces of the problem and related the criteria that the students brought up to the client's needs. He also talked to them about the trade-offs between criteria and the need to balance these trade-offs with completion of the challenge.

As his students progressed through the unit, Mr. Evans related the criteria, constraints, and client's needs more concretely to the problem they were trying to solve. For example, on day 16 within a discussion about how to evaluate their designs, he told the class:

> Ease of using construction, this is sort of subjective, but I want you to just kind of think about it, for example, if your design involves planting some trees and soil and some rocks, that's something that the farmer can do on his own, he probably doesn't have to hire anyone or get any help, right. Remember that was one of the stipulations that is easy to implement, right. If you're building some sort of glass dome, the farmer probably is going to have those skills and you're going to be kind of looking more in this general area where he's got the higher summative come out and build this dome and work with the glass and do all that.

In this example, Mr. Evans delved more deeply into how a specific criteria, ease of construction, could affect their design. By talking about the implications of their ideas, Mr. Evans encouraged his students to think about the entire system of the problem and the many components of the system that play into the solution.

Mr. Evans treated the client's problem as a real problem rather than just a classroom exercise that they need to solve. For example, at the beginning of the first lesson, he stated: "The next several weeks you are going to be acting as engineers as we face another challenge posed to us. We'll be working with the [University] like we kind of did with the space plants." In this example, Mr. Evans explained to students that they were like engineers and working for the university. He also explained that the university requires the students to do the work of engineers on a challenging problem. He treated the problem as a real problem that the students would be working on with the university. He continued to treat the engineering challenge as a real problem throughout the unit.

In addition to using problem scoping throughout the unit, Mr. Evans uses problem scoping on a smaller scale to frame many of his lessons. Mr. Evans integrated talk about problem scoping throughout each of his lessons. This is shown in Figure 2, which displays four example days.

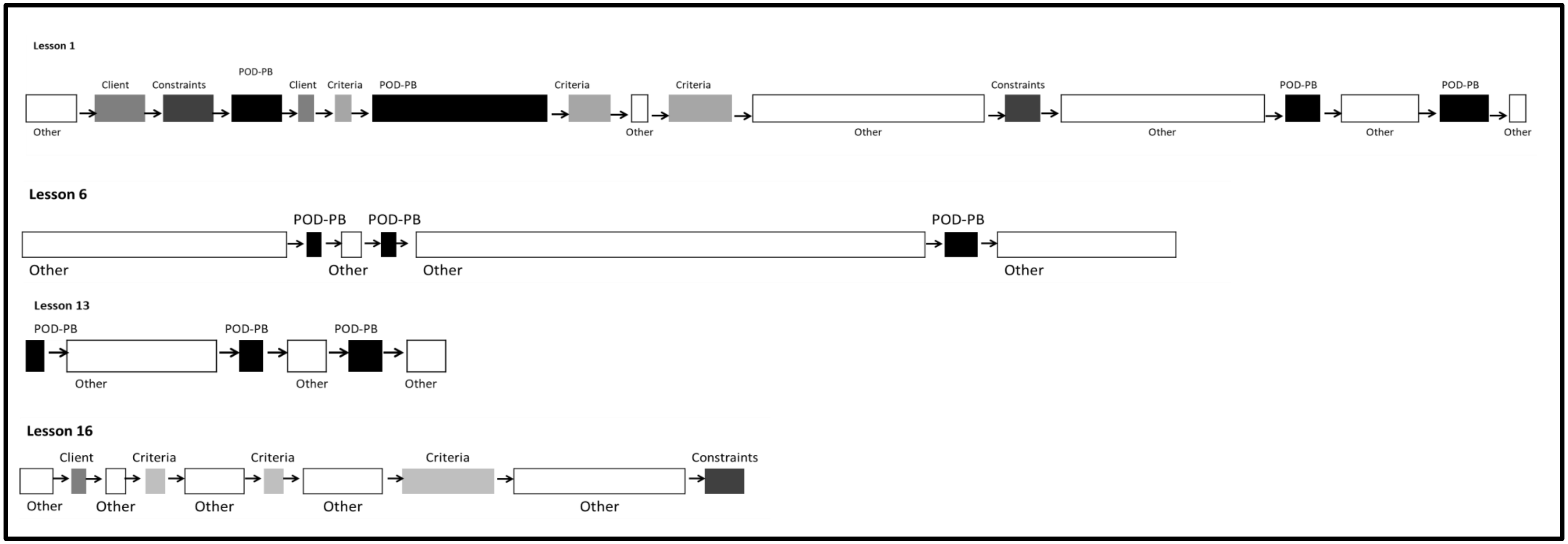

Figure 2. Examples of Mr. Evans' teacher talk about problem scoping on four example days at different point in the unit. Solid shading represents aspects of problem scoping. Empty boxes represent aspects of engineering talk that fall outside of problem scoping.

These example lessons demonstrate how Mr. Evans often returned to aspects of problem scoping in his teacher talk. These examples are representative of Mr. Evans' talk throughout the unit. On day 1, Mr. Evans spent a significant amount of time on aspects of problem scoping and bounced back and forth between different components of problem scoping. Because the students were introduced to the challenge on day 1 and most of this day was spent introducing the problem, the focus on problem scoping is expected. Mr. Evans continued to talk about aspects of the problem throughout the rest of the lessons. For example, on days 6 and 13, as students are learning the background science information they will need to solve the challenge, Mr. Evans integrated his talk about problem scoping into other engineering talk. He spends a period of time talking about other aspects of the challenge and periodically returns to talking about the problem. On day 16, as students were actively engaged in developing their solution, Mr. Evans talked more specifically about the criteria and constraints, but continued to integrate the problem scoping throughout the lesson.

Discussion and implications

Mr. Evans incorporated many key aspects of problem scoping into his teacher talk throughout the unit. Throughout the unit, he talked about the engineering challenge problem, client's needs, criteria, and constraints of the problem. He continued to talk through problem scoping for the entirety of the unit. This demonstrates for the students the importance of the continual process of problem scoping and that problem scoping does not end as the solution develops [14], [7]. Because student designers often do not realize the importance of problem scoping and do not spend enough time on it, it is important that Mr. Evans continued to talk about the problem and force his students to continue to think about it [7], [20], [24]. Mr. Evans also included the client and maintained the real-life nature of the engineering problem in many of his reminders of the problem, stressing to students that the engineering problem depends on the needs of the client [15]. Mr. Evans also integrated his problem scoping talk with other aspects of the unit as the unit progressed, emphasizing the iterative nature of problem scoping [23].

The teacher talk practices that Mr. Evans uses to frame his students' problem scoping have implications for other teachers, curriculum developers, and researchers of engineering design-based units. Mr. Evans was able to integrate problem scoping into his teacher talk to add to the authenticity of the engineering challenge, as well as model for his students many aspects of problem scoping. These findings have the potential to help teachers learn how to integrate problem scoping into their engineering instruction by incorporating it into their teacher talk.

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