AC 2011-735: THE NATURE OF TEACHER KNOWLEDGE OF AND SELF-EFFICACY IN TEACHING ENGINEERING DESIGN IN A STOMP CLASSROOM

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The Nature of Teacher Knowledge of and Self-Efficacy in Teaching Engineering Design in a STOMP Classroom

Curriculum standards increasingly feature engineering as a requirement for K-12 students. This is a content area in which most K-12 teachers have little to no background; therefore, providing support is critical for successful implementation. In an effort to provide support, the Tufts University Center for Engineering Education and Outreach (CEEO) founded the Student Teacher Outreach Mentorship Program (STOMP), which partners undergraduate majors and graduate engineering students with local teachers to design and implement engineering-design-based activities in their classrooms. These activities are tailored to topics that individual teachers want to address in his or her classroom, but all have the underlying theme of engineering design. Pairs of fellows, or undergraduate students, visit a teacher's classroom for an hour a week for eight to twelve weeks to implement these engineering-design-based activities. Teachers remain in the program for several years as learning of these topics is seen as a gradual process. The goals of STOMP are to provide teachers with the opportunity to (1) learn about and develop an appreciation for the professional field of engineering and technology; (2) gain confidence in teaching engineering and technology; and (3) develop conceptual tools for teaching engineering and technology.

The purpose of this paper is to examine teacher self-efficacy, engineering subject matter knowledge and pedagogical content knowledge in teachers enrolled in STOMP. Engineering is a broad content area. Engineering encompasses many different fields and bodies of knowledge. For this study engineering design as presented in the Massachusetts state curriculum frameworks will be the focus. Engineering design subject matter knowledge, or what a person knows about engineering design, and engineering design pedagogical content knowledge, or a amalgamate knowledge of engineering design, students and how the two interact, was measured using a hands-on think-aloud interview tasks that asked teachers to reflect on a hypothetical student design and observations of a STOMP classroom. To examine self-efficacy, an online engineering design self-efficacy survey was administered to teachers enrolled in STOMP and to teachers not enrolled in STOMP as a comparison group for analysis.

With the support of STOMP, it is possible that teachers develop knowledge of engineering design and feel more comfortable using engineering design in the classroom. Preliminary evaluation of this program shows that teachers feel STOMP helps them learn to use engineering in their classrooms. The results of this study show that STOMP does have a positive impact on teacher self-efficacy in teaching engineering design. In addition the more experience a teacher has with STOMP seems to impact the engineering subject matter knowledge and engineering design pedagogical content knowledge they applied in their interviews and classrooms.

Introduction

Concern over performance and participation in STEM (science, technology, engineering, and mathematics) fields in the United States has lead to greater integration and adoption of engineering in K-12 curricula. In December 2000, the Massachusetts Department of Education added engineering to its curriculum frameworks (as part of the Science & Technology/Engineering Curriculum Frameworks[2]). These requirements place a new responsibility on K-12 teachers to teach engineering, a topic in which many have no formal or informal background. The Tufts University Student Teacher Outreach Mentorship Program (STOMP) was founded in 2001 as a model for providing teachers with support in using engineering design in the classroom in the form of university students, or fellows, who study STEM topics at the university level[3]. Pairs of STOMP fellows collaborate with a K-12 classroom teacher to integrate engineering into their classroom.

The goals of STOMP are to provide teachers with the opportunity to (1) learn about and develop an appreciation for the professional field of engineering and technology; (2) gain confidence in teaching engineering and technology; and (3) develop conceptual tools for teaching engineering and technology. The purpose of this paper is to investigate whether any of these goals are met; specifically, whether STOMP has an impact on teacher self-efficacy in teaching engineering design and teacher engineering design subject matter and pedagogical content knowledge.

STOMP activities are hands-on engineering-based lessons co-designed by the pair of fellows and a teacher and that incorporate aspects of the engineering design process. There is no set curriculum for STOMP, teachers and fellows work together to address concepts that address the teacher's specific needs. The concepts addressed range from simple machines to electricity and to forces. However, the unifying theme of these activities is the engineering design process as presented in the Massachusetts Science and Engineering/Technology Curriculum Frameworks[3]. Pairs of STOMP fellows and teachers work together to implement these activities once a week for an hour for eight to twelve weeks over the course of one college semester.

Most STOMP teachers remain enrolled in the program for multiple years as the learning of these concepts takes time. It is thought that by providing teachers with content "experts", teachers have the opportunity to gradually learn about and incorporate engineering into their teaching. In the first year or two of the program, the classroom teacher takes on the role of a learner; they manage the class, but let the fellows teach the content as they learn alongside their students. As the teacher becomes more familiar and comfortable with the content, they gradually become more involved in teaching it. An objective of STOMP is for the classroom teacher to feel confident enough to become independent in teaching the content after several years of participation.

Theoretical Framework

STOMP as a Situated Learning Environment

One distinctive feature of STOMP is that teachers have the opportunity to learn about engineering in the context that they will eventually apply it. Unlike other types of professional development, which require that teachers apply and use content learned outside the classroom in the classroom, STOMP gives teachers the opportunity to explore how engineering-based activities look in their classroom before taking on the task of teaching them. STOMP does not require the teacher to attend any additional professional development workshops. This is thought to help teachers learn about engineering without adding to their already busy schedules.

The STOMP model provides teachers with a situated learning environment in which they have the opportunity to develop their knowledge and self-efficacy beliefs in the classroom context. The situated perspective stems from the Vygotskyian socio-cultural theory of learning in which learning is mediated through social interactions and influenced by culture[4]. Greeno notes that the social and cultural systems that influence learning are of great importance; therefore, the context in which a person learns a skill is a critical factor in their learning[5].

The importance is not *that* a learning activity is situated but *how* the learning is situated[5]. Greeno notes that "The situative perspective emphasizes aspects of problem spaces that emerge in activity, the interactive construction of understanding, and people's engagement in activities, including their contributions to group functions and their development of individual identities" (p. 14). A situated perspective recognizes that engineering in a classroom looks distinctly different from engineering in any other context because of the problems that arise, the interactions that take place, and the condition in which engineering is being used. The importance of teachers having the opportunity to learn engineering as they participate in engineering-based activities in their classrooms is that they learn how engineering content looks in a classroom setting, how students interact with the content and each other, and their role as a teacher in a hands-on, interactive teaching environment.

Self-Efficacy in Teaching Engineering in the Classroom

If a classroom teacher understands how engineering-based lessons look in a classroom before they pursue teaching these concepts on their own, they may have the time to develop higher self-efficacy, or confidence, in teaching engineering. Self-efficacy is a person's beliefs about what they are capable of achieving[6]. Since self-efficacy is domain specific, a teacher who has high self-efficacy in teaching math may not have the same level of self-efficacy in teaching engineering. Although teaching math, science, and engineering are closely related and often overlap, in looking at self-efficacy these teaching domains should be considered separate.

An important factor, which may influence teacher's self-efficacy in teaching, is how much they know about a domain. In teaching, subject matter knowledge has been shown to improve a teacher's self-efficacy in teaching that domain[6]. A potential explanation of this relationship is simply that the better a person feels that they know a topic, the better prepared they are to teach it and the more confident they will be in teaching it.

In domains such as engineering, with which teachers have very little previous experience, they may not feel that they know enough about the domain to successfully teach it[7]. The link between subject matter knowledge and self-efficacy is important in helping teachers learn to apply engineering concepts in teaching because they must know enough about the topic before they will feel confident in teaching it. Since self-efficacy can affect a person's persistence and success in a task[8], a critical factor in implementing engineering in the K-12 classroom is helping teachers build positive self-efficacy beliefs. A purpose of STOMP is to help teachers reach a level of comfort in teaching engineering by providing them with content support and by handing over some of the responsibility of teaching engineering to engineering undergraduates, so that teachers can practice applying engineering in the classroom over time.

Subject Matter Knowledge

To implement engineering into K-12 education, teachers must have some knowledge of engineering. However, the kinds of knowledge used in teaching engineering in the K-12 classroom must be identified to understand how to best prepare teachers for teaching engineering. Shulman considers subject matter knowledge (SMK) as one of three categories of teacher knowledge. "[SMK] refers to the amount and organization of knowledge per se in the mind of the teacher"[9]. Ball noted that understanding SMK for teaching has three main challenges; "what teachers need to know, how they have to know it, and helping them learn to use it" [10] .

The sources of teacher SMK range from primary school education, to college level preparation, to outside-of-school experiences. Hynes found several sources of middle school teachers' engineering SMK, including academic background in science and non-teaching experiences, but formal schooling was not a typical source of engineering SMK among teachers[8]. This can be attributed to the fact that engineering is not traditionally a topic that teachers encounter in their coursework. The source of SMK for teaching is important because different experiences provide opportunities to learn different facets of a subject. Although college level courses are a source of SMK, the subject matter taught in these courses often differs from the subject matter teachers are expected to teach at primary and elementary school levels[11]. STOMP may be a beneficial source of engineering SMK because the subject matter integrated into STOMP activities is appropriate for the age and level of their students.

The question of how much a teacher must know for teaching a subject is complex, as teachers must know a subject from different perspectives and for different purposes[12]. Teaching not only requires knowledge of the material that the students are expected to learn, but also understanding knowledge of that subject that would only be used in the context of a classroom. For example, a professional civil engineer does not need to be told that a bridge must be sturdy, it is implicit; but for teaching, this is a concept that may need to be made explicit. STOMP aims to be a source of SMK for teachers by dealing directly with the SMK that the teachers will use in their classrooms.

Pedagogical Content Knowledge

Shulman first used the term Pedagogical Content Knowledge (PCK) to describe a category of knowledge for teaching "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*"[9]. Aspects of teaching, such as knowledge of how students view and approach each topic, fall under the category of PCK[9, 13]. PCK recognizes that the knowledge necessary for teaching is unique from all other applications of a subject[9]. The way that students approach and use content to learn differs from how experts approach and use the same content; therefore, a teacher's role is to work with students' ideas and different views to help them learn how to use and apply new content[14].

The rationale behind teaching choices is not always apparent; a teacher may choose to approach a subject one way because of what she knows about what motivates her students or take a different approach based on her knowledge of how students interact with content[15]. These teaching choices are made in real-time in the classroom context; therefore, teachers must be adequately prepared in their PCK to make productive teaching decisions[9]. Since PCK is an internal construct, the depth of a teacher's PCK cannot be measured[16]. However, external evidence of teacher PCK is reflected in teachers' approaches to their students and their representations of knowledge[16, 9].

Although PCK is often informed by SMK, measuring SMK is not sufficient for understanding how a teacher uses their SMK in conjunction with their pedagogical knowledge[17]. This is the reason that Shulman calls PCK the "missing paradigm" in understanding how SMK and pedagogy are used together in the practice of teaching[9]. In engineering, it has been found that with the right support, such as content knowledge and feedback on progress, it is possible for teachers to develop engineering PCK[8]. In STOMP, it is possible that teachers develop engineering PCK by developing an understanding of how their students interact with engineering, which is reinforced by feedback from undergraduate fellows.

Research Methodology

This study will address the following questions:

1. What engineering design *subject matter knowledge* can be observed among teachers enrolled in STOMP?
2. What engineering design *pedagogical content knowledge* can be observed among teachers enrolled in STOMP?
3. What aspects of *self-efficacy* in teaching engineering design can be observed among teachers enrolled in STOMP compared to other teachers?

I hypothesize that as a result of STOMP providing content support in engineering design to teachers, which is an unfamiliar content area for most teachers, teachers will display and increase in engineering design subject matter knowledge and pedagogical content knowledge. I also hypothesize that as a result of their involvement in STOMP teachers will show self-efficacy beliefs that reflect positive views toward their abilities to teach engineering design

To examine self-efficacy, an engineering design self-efficacy survey was administered in the fall of 2010. The first part of the self-efficacy survey asked teachers background information to paint a picture of their experiences in teaching in general and in teaching engineering specifically. The second part of this survey is based on Carberry, Lee, and Ohland's Engineering Design Self-Efficacy Survey[18] and asks teachers to reflect on how good they think they are at teaching each step of the engineering design process in general and in the context of three separate engineering teaching activities: designing a sturdy structure, designing a catapult using levers, and designing a lifting device using gears. The survey was administered to the teachers enrolled in STOMP and to a second group of teachers not enrolled in STOMP as a comparison for analysis.

To measure subject matter knowledge and pedagogical content knowledge, videotaped classroom observations were collected of teachers during a STOMP class. As a complement to these observations, interviews were conducted of these same teachers using a modified version of Hynes's Hands-on Think-Aloud Interview tasks, in which teachers were asked to respond to hands-on tasks to assess how teachers go about solving these engineering teaching problems[8]. These tasks present teachers with a problem that a student might encounter and then they are asked to help the student resolve the problem based on their engineering and teaching knowledge. Hynes designed these tasks to reflect the curriculum on engineering design of assistive devices used in his particular study[8]. For this study, I kept a similar structure, but modified the design tasks to fit the STOMP areas of focus. Engineering design was the focus of the tasks; in STOMP, there is no single concept area that teachers focus on. In contrast, the one unifying focus is that of the engineering design process; therefore, the Hands-On Think-Aloud Interview tasks designed for the study presented in this paper ask teachers to explore the engineering design process. One task addressed a static system, where forces must balance for the structure to be sturdy, and the second task addressed a simple mechanics problem involving a wheel and axle. These results were complied into three case studies to compare teacher engineering deign subject matter and pedagogical content knowledge between teachers with different lengths of involvement with STOMP.

Results & Discussion

Survey: All Teachers

There are several interesting results from the teacher survey. Of 76 K-12 teachers, there was a fairly even distribution among high school teachers (n=25), middle school teachers (n=21) and elementary school teachers (n=30). The middle school teachers rated themselves better at teaching engineering design and each individual step of the engineering design process than both elementary and high school teachers, although the only differences that were significant were those with the elementary school teachers. The high school teachers rated themselves better at teaching engineering design and each step of the engineering design process than the elementary school teachers, although the only differences that were significant were those with the steps of the engineering design process (see Figure 1). These results show that the K-6 teachers are less confident than teachers in other grades in teaching engineering and therefore, may be at greater risk for avoiding the topic in their classrooms. These results also show that this population may be a worthwhile target for teacher professional development that focuses on using engineering in the classroom.

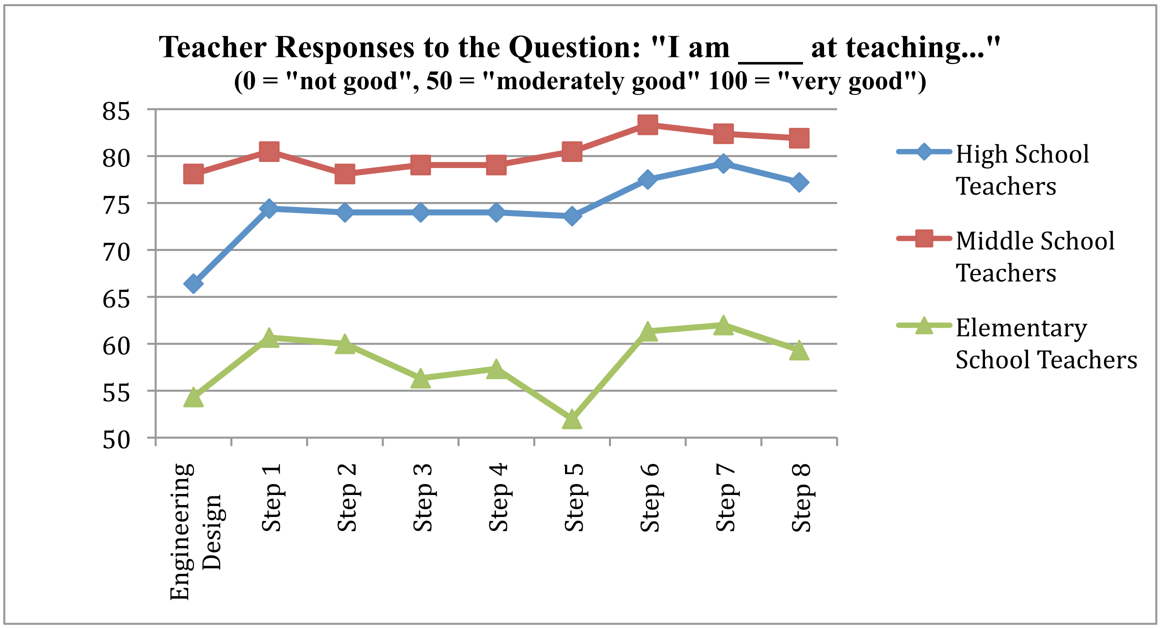


Figure 1. Teacher confidence in teaching engineering design and each of the 8 steps of the engineering design process.

Survey: STOMP Teachers

In comparing STOMP teachers to each other, those that have been participating in STOMP for 3 or more years (n=4) with those who had been participating for less than three years (n=5), the more experienced teachers, on average, rated themselves significantly better at teaching engineering design and steps 3 (develop a design solution) and step 5 (construct a prototype) of the engineering design process (see Figure 2).

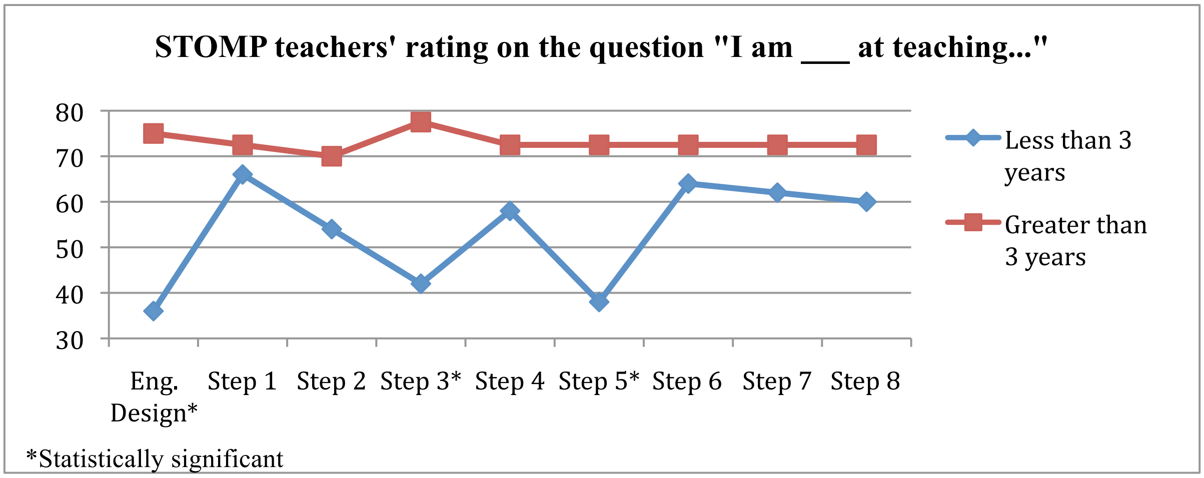


Figure 2. STOMP teachers' confidence in teaching engineering design and each step of the engineering design process.

When looking at questions that put engineering design in the context of problems involving sturdy structures, levers, and gears, more experienced STOMP teachers express more comfort at teaching the content. When asked to imagine a lesson in which their students design a structure to support the weight of a stack of books, the more experienced STOMP teachers rated themselves significantly better in applying the following steps of the engineering design process: step 4: select the best possible solution; step 6: evaluate and test a design; step 7: communicate a design; and step 8: redesign (see Figure 3).

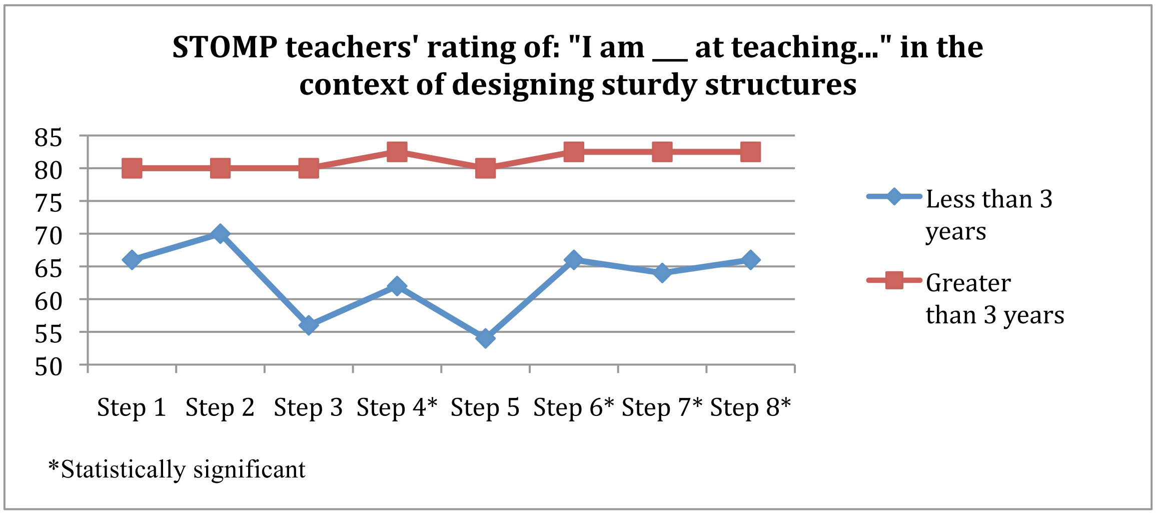


Figure 3. STOMP teachers' confidence in teaching engineering-based lessons involving sturdy structures.

When asked to imagine a lesson in which students were designing a catapult using levers in their design, experienced STOMP teachers rated themselves significantly higher in teaching the following steps of the engineering design process: step 1: identify a design need; step 2: research a design need; step 6: evaluate and test a design; and step 7: communicate a design (see Figure 4).

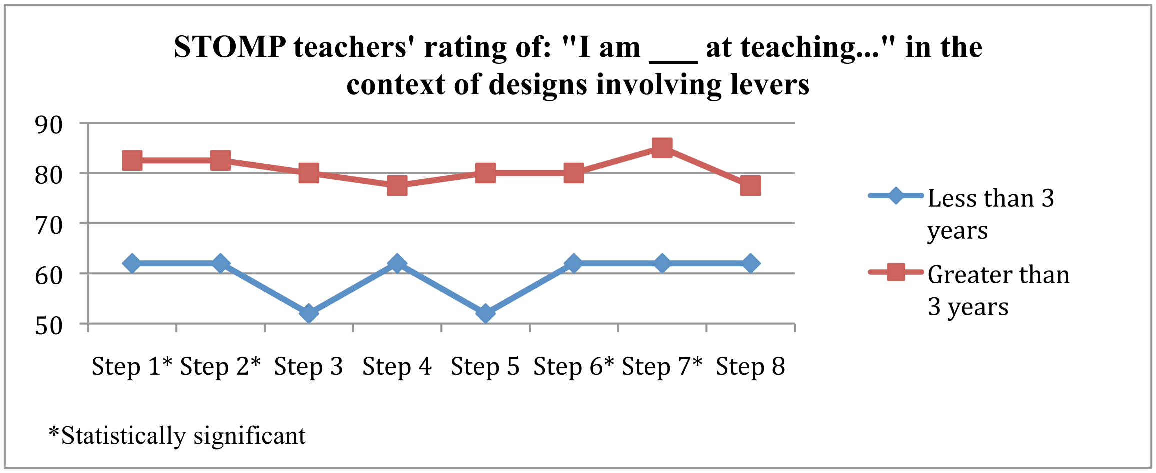


Figure 4. STOMP teachers' confidence in teaching engineering-based lessons involving levers.

When asked to imagine a lesson in which students design a device to lift a heavy object using gears, experienced STOMP teachers rated themselves significantly better at teaching the following steps of the engineering design process: step 2: research a design need; step 3: develop a design solution; step 4: select the best possible design; step 5: construct a prototype; step 6: evaluate and test a design; and step 7: communicate a design. Experienced STOMP teachers also rated themselves significantly better on average (85 compared to 52) at applying mathematics concepts to designs involving gears (see Figure 8).

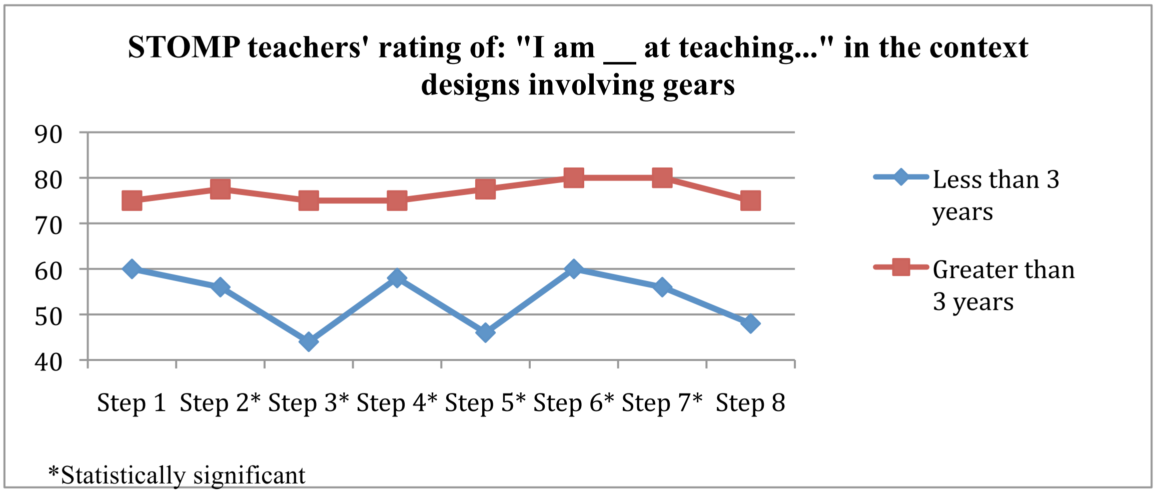


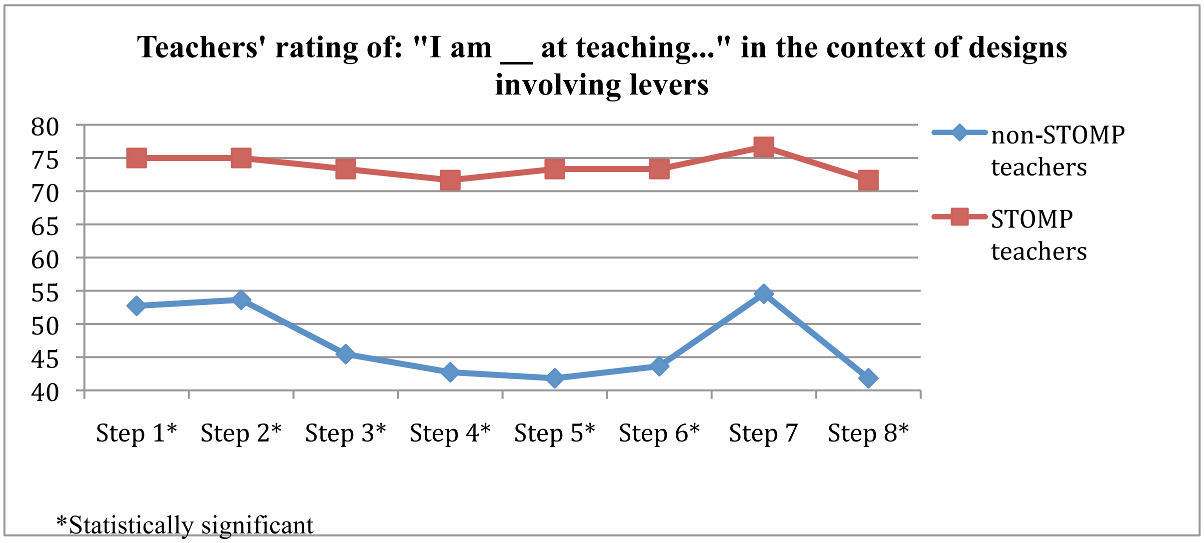
Figure 5. STOMP teachers' confidence in teaching engineering-based lessons involving gears.

The more veteran STOMP teachers self-reported greater confidence in teaching aspects of the engineering design process both in general and in the context of different types of activities. The gains seemed especially high in the context of designs involving levers and gears, in which experienced teachers felt significantly more confident in teaching 4 out of 8 and 6 out of 8 steps of the engineering design process respectively. It is possible that these teachers have had multiple experiences with these concepts in the STOMP classroom, which may have contributed to these gains in confidence. The more inexperienced teachers reported that they felt on average around the “moderately good” mark, whereas experienced STOMP teachers reported ratings that averaged closer to “very good”. These positive results show that STOMP may have a positive impact on teachers’ confidence in teaching engineering-based lessons.

Survey: STOMP vs. Non-STOMP Teachers

STOMP teachers enrolled in STOMP for more than one year (n=6) were compared to non-STOMP teachers with little to no background in engineering (n=12). STOMP teachers enrolled in STOMP for less than one year were not included in the STOMP teacher group because less than one year of STOMP is not thought to make a significant difference in a teacher’s comfort in teaching engineering. STOMP teachers rated themselves higher (61.7), but not significantly higher than non-STOMP teachers (42.5) at teaching engineering design. In general, STOMP teachers rated themselves higher in teaching all steps of the engineering design process, but this difference was only significant for step 5: construct a prototype.

In the context of teaching about sturdy structures, STOMP teachers rated themselves higher in teaching all eight steps of the engineering design process, but only significantly higher for step 4: select the best possible solution. In the context of levers STOMP teachers did rate themselves significantly higher at teaching the following steps of the engineering design process: step 1: identify a need or problem; step 2: research a need or problem; step 3: develop possible solutions; step 4: select the best possible design; step 5: construct a prototype; step 6: evaluate and test a design; and step 8: redesign (see Figure 6).



*Statistically significant

Figure 6. Teachers' confidence in teaching engineering-based lessons involving levers.

In the context of teaching about gears, STOMP teachers rated themselves significantly higher in teaching step 3: develop possible solutions; step 4: select the best possible solution; step 5: construct a prototype; and step 6: test and evaluate a design. Each teacher's rating of each step of the design process for teaching about sturdy structures, levers, and gears were averaged to come up with a score for teaching each step of the engineering design process in specific contexts. In teaching in the context of gears, levers, and sturdy structures, STOMP teachers rated themselves significantly higher for step 3: develop a design solution; step 4: select the best possible solution; step 5: construct a prototype; step 6: evaluate and test a design; and step 8: redesign (see Figure 7).

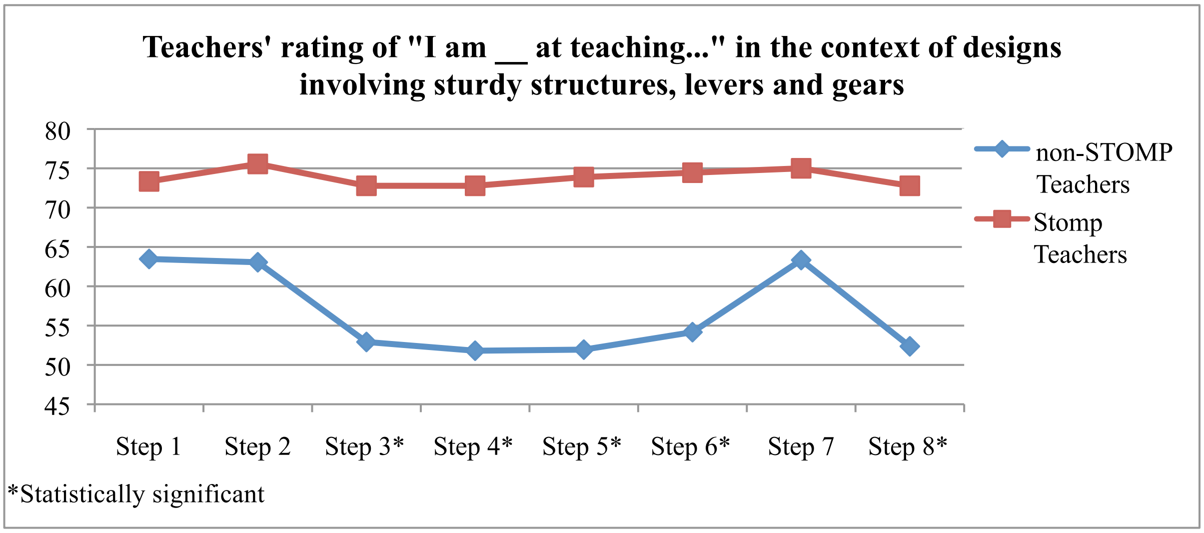


Figure 7. Teachers' confidence in teaching engineering-based lessons involving sturdy structures, levers, and gears.

In general, of all the steps of the engineering design process, teachers who are not enrolled in STOMP seem comfortable with step 1: identify a need/problem; step 2: research need/problem; and step 7: communicate, over the other steps of the engineering design process. It is possible that teachers without much engineering experience feel most comfortable with these steps because they are closely related to activities that teachers are familiar with teaching in other subject areas. Teachers may be familiar with teaching research and communication of results in other areas besides engineering, which may result in higher confidence in teaching these aspects of engineering. Teachers may be less familiar with other aspects of engineering design, such as selecting the best possible design solution, which may result in teachers being less confident in teaching these aspects of engineering design. STOMP teachers also rated themselves higher at applying science concepts to lessons involving sturdy structures and levers and significantly higher at applying math concepts to lessons involving gears (see Figure 8).

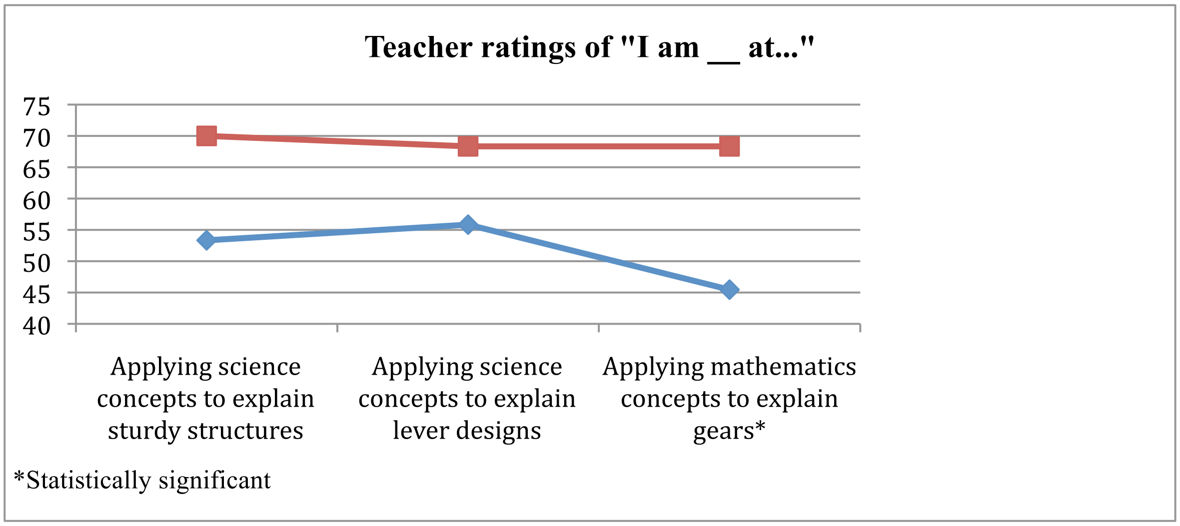


Figure 8. Teachers' confidence in applying science and mathematics concepts to sturdy structures, levers and gears.

In the STOMP classroom, teachers are often exposed to engineering design in the context of gears or levers. It is possible that through these experiences, teachers feel that they are better at teaching engineering-based lessons that involve these concepts. STOMP seems to be beneficial to teachers in that it gives them access to engineering lessons that are math or science based. As one teacher wrote in her survey:

"I have also realized that the some of the concepts I already teach have engineering in them."

Classroom Observations & Hands-on Interview Tasks

Five current STOMP teachers participated in classroom observations. These teachers were also interviewed to get a more holistic picture of their understanding of engineering. This paper will focus on three teachers: Mrs. Williams is a fifth grade teacher in her first year (second semester) of STOMP; Mrs. Davis is a fifth grade teacher in her third year of STOMP; and Mr. Lee is a fourth grade teacher who has participated in STOMP for ten years and also holds an undergraduate degree in engineering (all names are pseudonyms).

Case Study: Mrs. Williams, STOMP teacher in her 1st year of the program

Mrs. Williams was observed during one STOMP class in the Fall of 2010 in which students were exploring circuits. Although engineering design was incorporated into this lesson, the main content addressed was electricity. In the classroom, Mrs. Williams took on the role of a learner. She asked the STOMP fellows numerous questions about the activity as her class explored electric circuits and static electricity with two separate hands-on activities. For the first ten to fifteen minutes of the class, she stepped back and did not participate in teaching; however, as she became more comfortable with the activity, she asked her students about their ideas on what was going on in their designs and encouraged them to try out some of their more productive ideas. For example, she asked students to test out different object in the room to see if they were conductors or insulators.

Mrs. Williams did not display much *engineering* subject matter knowledge in the classroom. In one instance she used the word "prototype", but immediately checked in with a STOMP fellow to see if the use of the word was appropriate. On several instances she helped students think about testing different materials to see if they were conductors or insulators. She did use her subject matter knowledge of *electricity* quite often and elicited students' ideas about these concepts as she walked around the room. She displayed some, but not much engineering pedagogical content knowledge as she conducted a few mini-demonstrations to some of her students on testing their ideas. However, this lesson was more science than engineering focused, so on its own this lesson is not a good measure of this teacher's use of *engineering* subject matter knowledge.

However, the interview paints a clearer picture of Mrs. Williams engineering subject matter and pedagogical content knowledge. In her interview, Mrs. Williams was able to identify problems in the sturdy structure task Her understanding of what was going on in the sturdy structure task may have helped her come up with examples that might help her students identify problems in the sturdy structure:

"If I were going to use towers I'd, you know, have four legs to make it stable and it not tilt. Um, so I'd probably bring in, you know, ask questions about tables or desks, or um the counter [pointing around the room] and talk about some of the things that they have that might help you build."

However, she was not able to come up with an example in the rolling vehicle problem. When asked if she might use the engineering design process to help her students progress through the problem, she described the process of testing and evaluating (step 6) and redesigning (step 8) without directly referring to the steps:

"So I would have, just like, going through, what's going on here and what's making these wheels move quicker than these, and what can you do to change it and then I would say, well can we go through and test it and see if that works, and makes it any better?"

Mrs. Williams seems to still be building her engineering subject matter and pedagogical content knowledge. Although the activity that was observed was not as engineering focused as some other STOMP activities, she did not apply much engineering knowledge and relied more on her science knowledge. She also did not formally apply the engineering design process in addressing the interview tasks, but did seem to have an understanding of the processes involved in engineering design. There is very little evidence of her using pedagogical content knowledge in her classroom observation and in the interview she only displays engineering pedagogical content knowledge in the sturdy structure task in the interview.

In her survey, Mrs. Williams' results were typical of a non-STOMP teacher with little background in engineering. She rated herself to be "moderately good" for teaching engineering design in general (about 53 on average for all 8 steps) and engineering design in the context of levers and gears (50 on average for all 8 steps for levers and for gears). In the context of sturdy structures she rated herself slightly higher (about 63 on average for all 8 steps). She seems to feel slightly more confident in teaching in the context of sturdy structures, which she was also more comfortable with in the interview task. It is possible that she may have interacted with engineering in this context over her 2 semesters of participation in STOMP, which may have raised her confidence in teaching this specific topic.

Case Study: Mrs. Davis, STOMP teacher in her 3rd year of the program

In the classroom, Ms. Davis was very involved in teaching the content along with the STOMP fellows. Since her class was doing a lesson involving computers, she also spent a fair amount of time working out some of the technical issues. When she was not dealing with technical problems, she seemed to be able to jump right into the engineering content and help her students as they encountered problems.

In the lesson observed, students were selecting a design for a robotic mars rover based on a set of criteria they were given. Ms. Davis displayed *engineering* subject matter knowledge of what it means to make design choices and select the best possible solution. She explicitly asked her students to try and select the best possible solution and helped them identify the strengths and weaknesses of different designs. As this lesson is focused on this one step of the engineering design process, she did not have much reason to refer to other aspects of the engineering design process. Ms. Davis also displayed *engineering* pedagogical content knowledge in her class by using visual representation to help students think about selecting the best possible solution. She drew a chart of students' rover design choices and their reasons for choosing each design on the board as they reviewed the lesson.

Ms. Davis often referred to the engineering design process in her interview. She was able to identify problems in the sturdy structure task, such as the weight distribution was contributing to stability problems in the design. She was also able to come up with ways that she would help students think about the distribution of the weight and about balance in the structure:

"Could I use [the structure] for everything, or does [the object it is supporting] have to be a certain diameter, so I would bring a little math into it."

In the rolling vehicle task, Ms. Davis was able to quickly identify that friction was causing the wheels not to turn. She was able to quickly come up with ways for her students to think about friction:

"Talking about rubbing your hands together, it heats up…I might take even, like a piece of string, you know and if you have the string out here [holding her hands as if she was grasping a rope, but far apart] does it work better? ... Or if you put it here [holding her hands as if she was grasping a rope, but close together] does the string work better?"

In contrast to Mrs. Williams, Ms. Davis showed greater use of the engineering design process in both her observed lesson and her interview. She seemed to naturally apply engineering to each task. She also displayed engineering pedagogical content knowledge through her use of a visual representation in the classroom to help her students think about selecting the best possible solution and by coming up with ways to help her students think about the concepts present in the sturdy structure and rolling vehicle tasks.

In her survey, Ms. Davis reported feeling "moderately good" at teaching engineering in general (about 41 on average for all 8 steps). However, she rated her self much higher in the context of teaching about sturdy structures (about 76 on average for all 8 steps), levers (about 78 on average for all 8 steps), and gears (74 on average for all 8 steps). These results seem to indicate that through STOMP, Ms. Davis has gained confidence in teaching engineering in the context of sturdy structures, levers, and gears, but she is not yet confident in applying engineering design to other contexts.

Case Study: Mr. Lee, STOMP teacher in his 10th year of the program

In his classroom observation, Mr. Lee's students were designing and testing robotic vehicles. In the classroom, Mr. Lee took on a role as a co-teacher along with the STOMP fellows. Unlike Mrs. Davis and Ms. Williams, Mr. Lee led parts of the lesson introduction.

Mr. Lee frequently refocused his students on steps 6 (evaluate and test a design) and step 8 (redesign) of the engineering design process, which were the focus of this lesson. Although he only formally referred to testing, he frequently encouraged students to evaluate their designs, diagnose problems, and redesign accordingly. He helped students identify symmetry and frictions in their designs. Mr. Lee used examples, analogies, and mini-demonstrations to help his students design sturdy vehicles and think about the design process. He also helped students by identifying and encouraging students to pursue productive ideas.

In his interview, Mr. Lee was able to identify problems in both the sturdy structure task and the rolling vehicle task. He was also able to discuss how he would encourage his students to use the engineering design process to think about how to evaluate, make changes and improve on the design. He was able to come up with analogies for each situation to help students think about the design task.

Mr. Lee seems to have developed engineering subject matter and pedagogical content knowledge. He appropriately applied the engineering design process in the STOMP classroom and in his interview. He recognized the concepts of symmetry and friction in his students' work and in the interview tasks. Mr. Lee was able to come up with analogies, examples and demonstrations much more frequently in the classroom than the other two teachers. He also came up with appropriate examples in his interview and identified how the examples were useful and how they were not. For example, in helping students think about friction, Mr. Lee said:

"I would demonstrate to them, yeah, like that, rubbing their hands, or also, yeah, for example, in walking situations…when we walk, yeah, because of the friction we can move around like that [moving feet]. But it's a little bit different from the wheel, the situation that goes faster."

In this quote, Mr. Lee recognizes that friction is a force that students encounter on a daily basis. He notes that friction is what keeps our feet on the ground and what we use to move ourselves forward as we walk. He also noticed that his analogy might be slightly confusing for the students because in the rolling vehicle task the aim is to *reduce* friction.

Mr. Lee reported very high confidence in teaching engineering design in general (79 on average for all 8 steps) and in the context of sturdy structures, levers, and gears (80 on average for all 8 steps for each context). His survey results show that he feels comfortable both when engineering design is put into context and just in general. This indicates that his experience may have contributed to him becoming more confident in applying engineering design in general, not just in a context that would be seen in a typical STOMP engineering activity (sturdy structures, levers, and gears).

Case Studies Compared

Mr. Lee seemed to be very comfortable in using engineering design in his classroom and in the interview task. In the interview, he identified several problems with the sturdy structure task and the rolling vehicle task. Ms. Davis was also able to identify problems in both the interview tasks, but not as many as Mr. Lee. Mrs. Williams struggled with the interview tasks and was not able to identify the problems in the rolling vehicle problem.

In the classroom, Mr. Lee's use of the engineering design process was much more frequent than in Mrs. Williams or Ms. Davis's classroom. However, this may have been a result of the type of activity being enacted in each observation. A better measure of this would be to conduct observations of the same lesson. Unfortunately, STOMP does not have a set curriculum and the activities enacted in each classroom each semester are often very different.

In comparing the results from the three surveys, there are a few interesting trends. First, elementary school teachers self-reported significantly lower confidence in teaching engineering design, which shows that efforts to help teachers learn to use engineering design in their classrooms should be focused on this group. Another interesting trend is that teachers seem to first develop confidence in teaching in contexts that are often used in STOMP activities; applying engineering to the design of sturdy structures, levers, and gears. The challenge of teaching engineering design in general, or to contexts that teachers may not encounter in their STOMP classroom seems to come with more STOMP experience.

The fact that teachers are less confident in teaching engineering design in general shows that improvement could be made to the STOMP model to help teachers apply engineering design concepts to a wider range of topics. Although teachers seem to become very familiar with the activities they use in the STOMP classroom, if a goal is to help teachers become independent, than helping teachers apply engineering design to different topics will be important. It is possible that teacher workshops, run by engineering education experts, which help teachers reflect on what they do in the classroom may be one way to address this issue.

Overall, STOMP teachers displayed subject matter and pedagogical content knowledge in their classroom observations and interviews. From these three case studies, there is evidence that a teacher with more years of participation in STOMP was better able to use subject matter and pedagogical content knowledge in the classroom observations and in the hands-on interview tasks.

Conclusion & Future Considerations

The results of this study indicate that teachers in grades K-6 may be most in need of experiences that will boost their confidence in teaching engineering and provide them with opportunities to build their engineering subject matter and pedagogical content knowledge. If curriculum standards place the responsibility of teaching engineering on K-6 teachers, understanding how to best prepare these teachers is critical.

This study indicates that STOMP may be one type of experience that allows teachers to develop their subject matter knowledge, pedagogical content knowledge, and self-efficacy in teaching engineering design. The results also seem to indicate that these teaching qualities take several years to develop through the STOMP model. Complementary experiences, such as professional development workshops, that are coupled with STOMP may accelerate these positive results.

Further studies that investigate how to best prepare teachers for teaching engineering content in the classroom will be an important accompaniment to this one. Further study of STOMP and its impact on student learning is also important for a more complete understanding of the program. Longitudinal data on STOMP and how individual teachers change over the course of their enrollment in the program will also give a better idea of how the program impacts teachers.

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Appendix A: Online Teacher Survey
Surveys will be administered online using Survey Monkey (www.surveymonkey.com)

Part A: Consent

[Posted PDF of consent to participate in the online survey form]

I consent to participate in this study by typing my initials in the box below and selecting agree

Initials:_____________
__agree
__disagree

Part B: Background Information

Directions: *Please answer the following questions on your background and your background in engineering as best you can. Questions marked with an asterisk require an answer.*

1. What is your involvement with the Tufts University Student Teacher Outreach Mentorship Program?* (choose one)
    ___ I am not involved
    ___ I have been involved with STOMP in the past
    ___ I am currently involved in STOMP

2. What grade(s) do you teach?* (check all that apply)
    ___ 1st
    ___ 2nd
    ___ 3rd
    ___ 4th
    ___ 5th
    ___ 6th
    ___ 7th
    ___ 8th
    ___ 9th
    ___ 10th
    ___ 11th
    ___ 12th
    ___ Other, Please specify:

3. Gender
    ___ Male
    ___ Female

4. To what degree would you say you use engineering concepts in your classroom? (choose one)
    ___ None
    ___ Very Little (once or twice a semester/year)
    ___ A Moderate Amount (once a month)
    ___ Often (once a week)
    ___ Quite often (more than once a week)

___ Other, Please specify:___________________

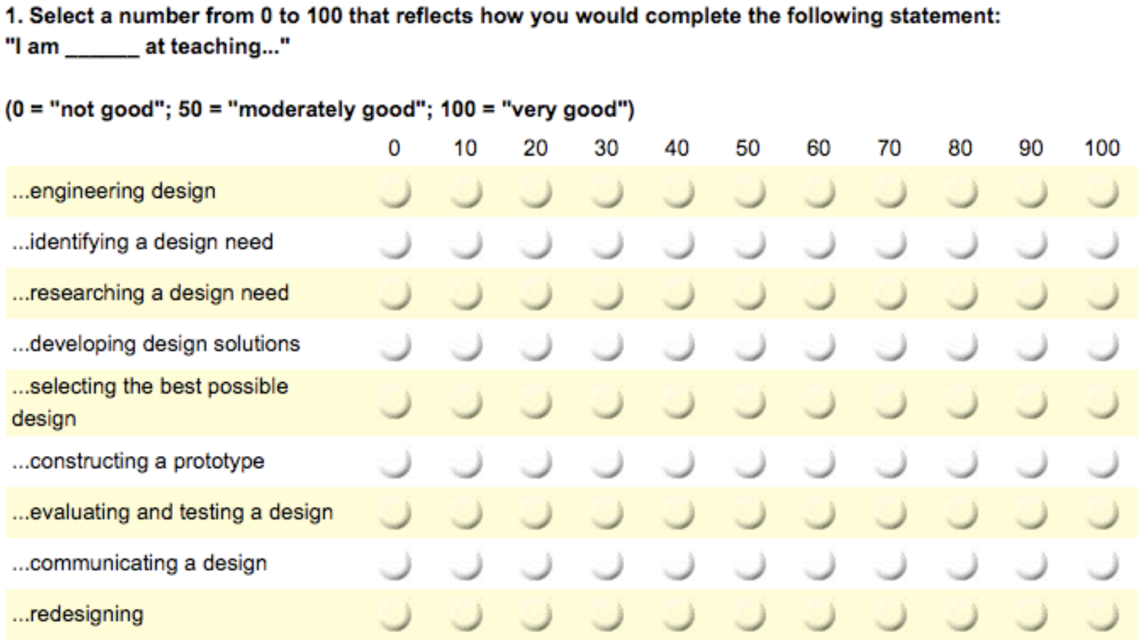
5. What is your background in engineering? (check all that apply)
   ___ I have no background in engineering
   ___ I have participated in professional development workshops in engineering education
   ___ I am familiar with the field through informal experiences
   ___ I have formal schooling in the field from my K-12 education
   ___ I have formal schooling in the field from my undergraduate education
   ___ I have formal schooling in the field from my graduate education
   ___ I am a science major
   ___ I am a mathematics major
   ___ I am an engineering major
   ___Other, Please specify:________________________________

6. If you have been involved in STOMP in the past or are currently involved in STOMP what (if anything) do you feel that you have you gained from your STOMP experience?

7. What do you feel are the challenges in adopting engineering in K-12 classrooms?

Part C: Teaching engineering design

Directions: *Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.*



1. Select a number from 0 to 100 that reflects how you would complete the following statement:
"I am ______ at teaching..."

(0 = "not good"; 50 = "moderately good"; 100 = "very good")

	0	10	20	30	40	50	60	70	80	90	100
...engineering design	○	○	○	○	○	○	○	○	○	○	○
...identifying a design need	○	○	○	○	○	○	○	○	○	○	○
...researching a design need	○	○	○	○	○	○	○	○	○	○	○
...developing design solutions	○	○	○	○	○	○	○	○	○	○	○
...selecting the best possible design	○	○	○	○	○	○	○	○	○	○	○
...constructing a prototype	○	○	○	○	○	○	○	○	○	○	○
...evaluating and testing a design	○	○	○	○	○	○	○	○	○	○	○
...communicating a design	○	○	○	○	○	○	○	○	○	○	○
...redesigning	○	○	○	○	○	○	○	○	○	○	○

2. Imagine that your class is designing a structure to support the weight of a stack of textbooks. Select a number from 0 to 100 that reflects how you would complete the following statement:
"I am ______ at teaching about..."

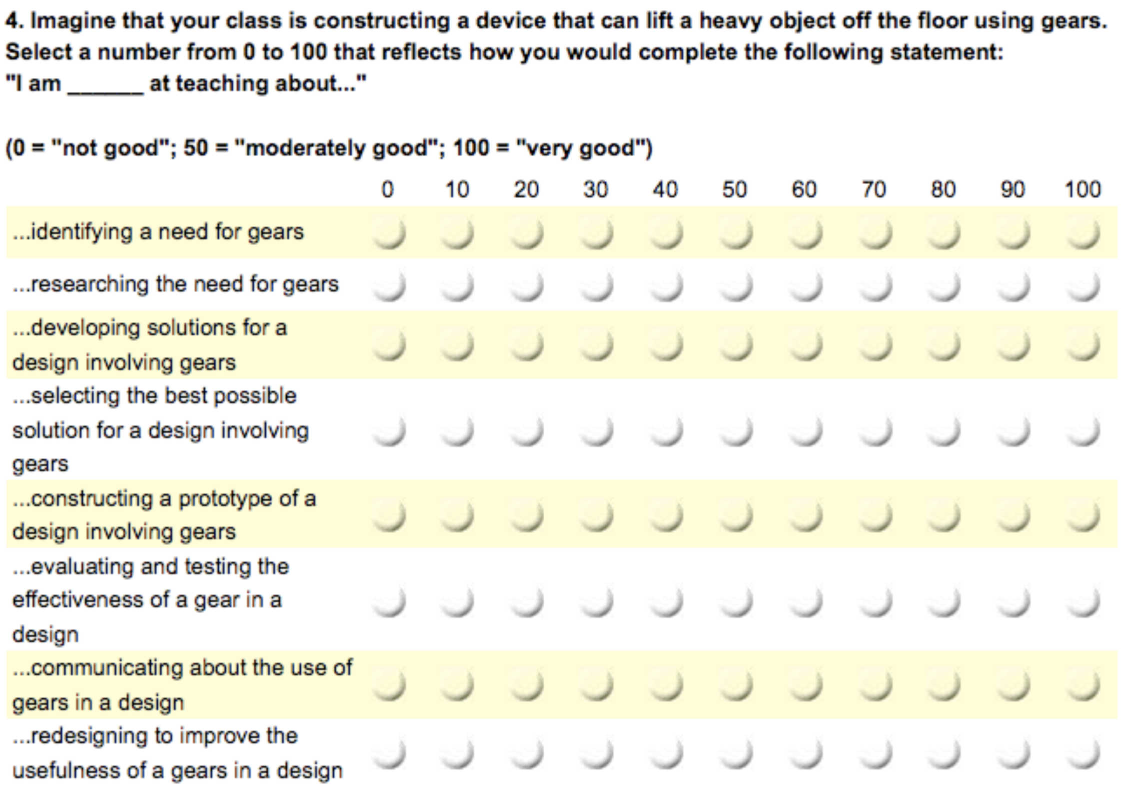
(0 = "not good"; 50 = "moderately good"; 100 = "very good")

	0	10	20	30	40	50	60	70	80	90	100
...identifying a need for a sturdy structure	○	○	○	○	○	○	○	○	○	○	○
...researching the need for sturdy designs	○	○	○	○	○	○	○	○	○	○	○
...developing design solutions for sturdy structures	○	○	○	○	○	○	○	○	○	○	○
...selecting the best possible sturdy structure design	○	○	○	○	○	○	○	○	○	○	○
...constructing a prototype of a sturdy structure	○	○	○	○	○	○	○	○	○	○	○
...evaluating and testing a design for sturdiness	○	○	○	○	○	○	○	○	○	○	○
...communicating about a sturdy design	○	○	○	○	○	○	○	○	○	○	○
...redesigning to improve sturdiness of a structure	○	○	○	○	○	○	○	○	○	○	○

3. Imagine that your class is designing a catapult to launch an object as far as possible, using levers in their designs. Select a number from 0 to 100 that reflects how you would complete the following statement:
"I am ______ at teaching about..."

(0 = "not good"; 50 = "moderately good"; 100 = "very good")

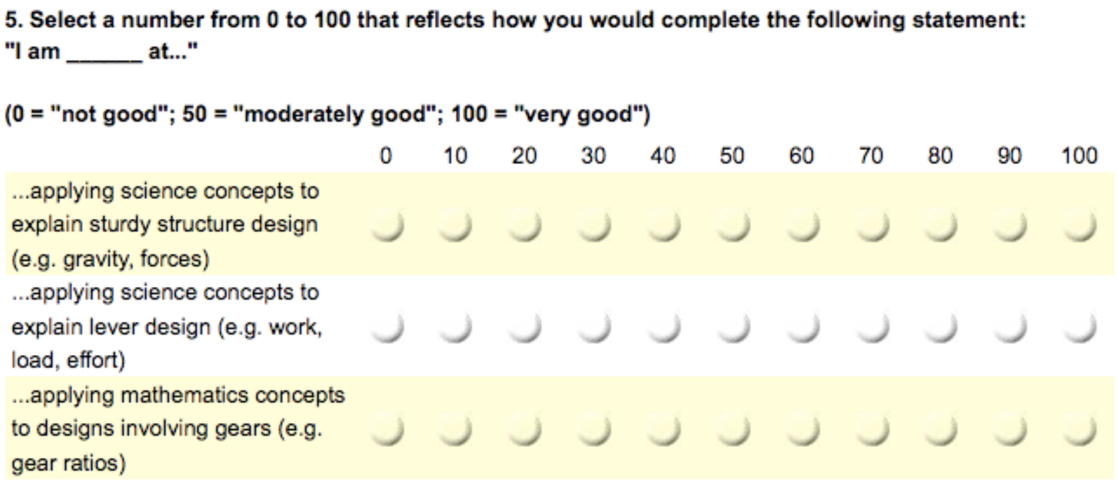
	0	10	20	30	40	50	60	70	80	90	100
...identifying a need for a lever	○	○	○	○	○	○	○	○	○	○	○
...researching a lever design	○	○	○	○	○	○	○	○	○	○	○
...developing solutions for a design involving levers	○	○	○	○	○	○	○	○	○	○	○
...selecting the best possible solution for a design involving levers	○	○	○	○	○	○	○	○	○	○	○
...constructing a prototype of a design involving levers	○	○	○	○	○	○	○	○	○	○	○
...evaluating and testing the effectiveness of a lever in a design	○	○	○	○	○	○	○	○	○	○	○
...communicating about the use of levers in a design	○	○	○	○	○	○	○	○	○	○	○
...redesigning to improve the usefulness of a lever in a design	○	○	○	○	○	○	○	○	○	○	○



4. Imagine that your class is constructing a device that can lift a heavy object off the floor using gears. Select a number from 0 to 100 that reflects how you would complete the following statement:
"I am ______ at teaching about..."

(0 = "not good"; 50 = "moderately good"; 100 = "very good")

	0	10	20	30	40	50	60	70	80	90	100
...identifying a need for gears	○	○	○	○	○	○	○	○	○	○	○
...researching the need for gears	○	○	○	○	○	○	○	○	○	○	○
...developing solutions for a design involving gears	○	○	○	○	○	○	○	○	○	○	○
...selecting the best possible solution for a design involving gears	○	○	○	○	○	○	○	○	○	○	○
...constructing a prototype of a design involving gears	○	○	○	○	○	○	○	○	○	○	○
...evaluating and testing the effectiveness of a gear in a design	○	○	○	○	○	○	○	○	○	○	○
...communicating about the use of gears in a design	○	○	○	○	○	○	○	○	○	○	○
...redesigning to improve the usefulness of a gears in a design	○	○	○	○	○	○	○	○	○	○	○



5. Select a number from 0 to 100 that reflects how you would complete the following statement:
"I am ______ at..."

(0 = "not good"; 50 = "moderately good"; 100 = "very good")

	0	10	20	30	40	50	60	70	80	90	100
...applying science concepts to explain sturdy structure design (e.g. gravity, forces)	○	○	○	○	○	○	○	○	○	○	○
...applying science concepts to explain lever design (e.g. work, load, effort)	○	○	○	○	○	○	○	○	○	○	○
...applying mathematics concepts to designs involving gears (e.g. gear ratios)	○	○	○	○	○	○	○	○	○	○	○

Part D: Short Answers about Engineering Design

Direction: *Please provide a short answer (1 – 2 sentences) to each question about the engineering design process.*

1. Give an example of when an engineer would want to use a prototype:

2. What is the importance of redesign in engineering?

3. Would it be okay for an engineer to skip from step 6 (evaluate and test a design) to step 4 (select the best possible design) in the engineering design process when trying to solve an engineering design problem? Why or why not?

Thank you!
Appendix B: Teacher Interview

Question1: Identifying Sturdy Structures
This task is designed to identify a teachers' knowledge of statics, or structures that are designed to balance a force.

Give teachers an example tower (LEGO) that is supposed to hold up the weight of a book off of the table.

1. Your student shows you this structure and complains that it is not holding up a book as it is supposed to. Students ask why their tower is not working? Can you identify some possible reasons that this structure is not holding up the weight?
2. Second, how would you guide the student without directly give them the answer? What math, science, or engineering concepts would you bring up and describe to the student?
   How might you use the engineering design process to guide the student?
   What are some examples or analogies that you could use to help students understand these concepts?

3. Possible follow-up questions based on responses

Question 2: Simple Machines
This task is designed to identify teachers' knowledge of a mechanics problem involving a simple machine.

Give the teacher an example car with a non-symmetric axle that does not spin correctly the car

1. Your student shows you this car and asks why it doesn't go as fast as the other group's car, which looks the same. First, can you identify some possible reasons why this car is not going as fast as another team's car?

2. Second, how would you guide the student without directly giving them the answer? What math, science, or engineering concepts would you bring up and describe to the student?

   How might you use the engineering design process to guide the student?

   What are some examples or analogies that you could use to help students understand these concepts?

3. Possible follow-up questions based on responses.
4.

Question 3: Follow up on classroom observation

1. In my observation, I noticed_________ can you explain/elaborate/reflect on your approach?
2. Follow-up questions based on responses

Question 4: Follow up on Survey Data

1. In your survey, I noticed you responded ____________ Can you explain/elaborate/reflect on this response?
2. Follow-up questions based on response

Question 5: What do you feel are challenges in adopting engineering into K-12 classrooms?
Follow–up questions based on response