AC 2010-207: WHAT CAN TEACHERS LEARN FROM ENGINEERING EXPERTS? USING A THREE-PHASE MODEL TO IMPROVE K-12 TEACHER'S KNOWLEDGE OF ENGINEERING AND TECHNOLOGY

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What can teachers learn from engineering experts? Using a three-phase model to improve K-12 teacher's knowledge of engineering and technology

Abstract

A convenient way to improve K-12 teachers' understanding of engineering and technology is to use experts in these areas as resources. The Tufts University Student Teacher Outreach Mentorship Program (STOMP) model forms collaborations between undergraduate or graduate students and classroom teachers to take advantage of each party's expertise. These undergraduate and graduate students, or STOMP fellows, study science, technology, engineering, and math (STEM) subjects at the university level and can be considered experts in these subject areas because of their constant exposure to, and knowledge of these topics. As experts, they share their knowledge with teachers to help teachers build an understanding of, and comfort level with engineering and technology. The end goal of this partnership is to provide a teacher with the knowledge, tools, and confidence to implement an engineering and technology curriculum in their classroom.

In this paper we examine teachers' reactions on their participation in STOMP. We specifically look at teacher perceptions of STOMP, experience and comfort level in teaching STEM content, and their shear interest in the STOMP program. We also examine a need and rationale behind a three-phase model in which STOMP has a sustainable impact on a teacher's ability to implement STEM curricula.

Results of this study show that STOMP has raised teachers' confidence in teaching and knowledge of engineering and technology content. These results support the use of a three-phase model to create a sustainable program that empowers teachers to gain independence in teaching in these previously unfamiliar content areas.

Introduction

The Tufts University Student Teacher Outreach Mentorship Program (STOMP) is an outreach program designed to assist K-12 teachers in integrating engineering and technology across all disciplines.[1] The program was founded in 2001 as a response to the incorporation of engineering and technology into the Massachusetts' Science & Technology/Engineering Curriculum Framework.[2] The additions to the framework placed new responsibilities on teachers who had little previous engineering and technology experience. K-12 teachers are not necessarily expected to become experts in each field they teach, but are expected to be proficient enough to use the knowledge that they teach. In expertise literature it is thought that 100 hours of learning and practice is necessary to reach proficiency.[3] A teacher involved in STOMP, over a 5-year period, will reach this 100-hour milestone.

STOMP helps equip teachers to teach these unfamiliar content areas by providing them with STEM "experts" in the form of university students, or STOMP fellows. University students, while not yet professionals in their fields, can be considered to have reached the level of skill acquisition needed for use in a K-12 classroom setting.[4] Over time, a STOMP fellow-teacher collaboration can provide teachers with the expertise and tools necessary to overcome low confidence, which may inhibit their ability and willingness to teach these topics.[5]

For the purposes of this paper, we will be examining aspects of STOMP regarding K-12 teachers' acquisition of STEM content knowledge. We will specifically look at engineering and technology, which are the most recent additions to the Massachusetts' Curriculum Frameworks.[2] We will take a closer look at the three-phase model that governs the program and the roles of the K-12 teacher. We will also investigate how this program affects teacher self-efficacy, perceptions, and interest regarding the teaching of engineering and technology.

Theoretical Framework

To ensure that teachers gradually acquire the knowledge, skills and tools necessary for teaching engineering and technology on their own, we have developed a model that aligns closely with Collins, Brown & Newman's cognitive apprenticeship model.[6] Apprenticeship is a form of situated learning where "knowledge and skill develop in the process",[7] and through social activity.[8] Traditional apprenticeships were used to train novices in a skill or trade, such as in carpentry. Through traditional apprenticeships, a person would learn the processes of a skill through observation, gradual use, and approximation of the skill.[6]

Cognitive apprenticeship is a term that was first used by Collins, Brown & Newman to describe the use of apprenticeship methods to teach cognitive processes and knowledge rather than a skilled trade.[6] In a cognitive apprenticeship, knowledge acts like a tool that can be used and applied.[9] According to Collins, Brown & Newman's cognitive apprenticeship model, there are four types of knowledge required for expertise: 1) domain knowledge - facts, procedures and content knowledge in an area of study; 2) heuristic strategies - methods involved in the accomplishment of the desired task; 3) control strategies - knowing how to apply methods for accomplishing a task; and 4) learning strategies - the abilities of the learner to learn new information, methods, and practices in a domain.[6] STOMP is an appropriate application of the cognitive apprenticeship model because the teacher learns engineering and technology content knowledge in a situated learning context in which they are expected to use this knowledge.[6]

STOMP Three-Phase Model

Using the cognitive apprenticeship model, a three-phase STOMP model was designed around Anderson's theory of acquisition of cognitive skills,[3] and Fitts & Posner's theory on acquisition of expertise.[4] Depending on a teacher's individual progress, the process can last between 3 - 5 years, and follow the general order of:

Phase I (Year 1-2): Expert teaches while the teacher learns new content

Phase II (Year 2-4): Expert and teacher co-teach STEM content

Phase III (Year 3-5): Teacher teaches while the expert provides content support

Phase I: Teacher as Learner, Fellow as a Model

The role of the teacher in the first phase is to observe and learn while the fellow models their engineering and technology content knowledge through teaching. The purpose of this phase is to allow the teacher to become comfortable with the domain knowledge by observing the use of content-specific heuristic strategies in action. An opportunity to observe an expert model allows the teacher to step back from teaching and examine the expert using this knowledge in solving problems and design tasks.

According to Fitts & Posner, this stage of expertise acquisition is called the cognitive stage.[4] In the cognitive stage, the learner must acquire the knowledge necessary for replication of a skill.[4] Anderson describes this process as the declarative stage when applied to a cognitive skill. The declarative stage is when the learner processes knowledge into working memory so that they can interpret the facts as they are used in procedures.[3] This phase allows the teacher to rehearse the facts as they are being used without the cognitive burden of having to apply the information themselves.

The first phase in which the teacher observers and the fellow models their knowledge also closely aligns with modeling as described by cognitive apprenticeship. In a cognitive apprenticeship, the observer constructs a conceptual model of the processes required to carry out a task as the expert models these processes.[10] Bandura believes that expert models are particularly motivating to others.[11] Models can serve as markers of progress or vicarious experiences. Schunk states, "observing similar others succeed at a task can raise observers self-efficacy and motivate them to try the task themselves…".[12] According to Bandura "efficacy expectations determine how much people will expend and how much people will persist in the face of obstacles and adverse experiences".[13] When people have little basis for judging their progress and comparing their abilities they will be more likely to avoid the situation.[14] This in turn may affect the time and effort a teacher will invest in teaching these topics.

Situated learning theory emphasizes the importance of modeling as well. Bandura states, "from observing, one forms a conception of how new behavior patters are performed.".[13] Observing an expert model their knowledge in the context that the knowledge will be used is important for the observer to be able to apply their conception of how to use the content knowledge and carry out a task in the future. The social and cultural context that information is modeled in is crucial for the information to be useful to the observer.[15] In a STOMP classroom, the teacher is observing engineering and technology being used in a classroom context; the same context in which they are expected to replicate its use in the future. According to situated learning theory, this is a much more effective method for teachers to acquire engineering and technology content than reading about the content in a book, or by observing engineers in a professional environment.[7]

Phase II: Co-Teaching, Fellow as a Coach

Bandura notes that a person can evaluate their progress, knowledge, learning, and performance when transitioning from a state of observation to an active state of using newly acquired knowledge.[13] As such, the second phase of the STOMP three-phase model is an opportunity for collaborative teaching by the STOMP fellow and classroom teacher. This phase is a first attempt by the teacher to teach the content when he or she feels comfortable doing so. The fellow continues to be heavily involved by providing the teacher with resources for teaching and feedback on their use of STEM knowledge in these activities. Only when the teacher does not feel comfortable doing so does the fellow take on the role of teacher.

In Fitts & Posner's model, the second phase of skill acquisition is called the associative stage and is the process by which a person's knowledge of a skill gradually becomes procedural.[4] Anderson terms this process as knowledge compilation when applied to knowledge acquisition.[3] Knowledge compilation is the process by which declarative knowledge becomes useful to the learner as procedural knowledge through successive approximations of its use.[3]

Bandura believes that feedback on performance or use of knowledge is important for reflection on that process.[13] In a cognitive apprenticeship this feedback process is described as coaching.[6] During coaching, the expert's role is to observe the learner execute a task and offer feedback on the learner's development.[6] The expert should coach the learner's attempts at using knowledge in a relevant context because acquiring the use of a cognitive tool requires the actual use of that tool in context.[9]

Phase III: Teacher as Expert, Fellow Fades Support

The last phase of the STOMP three-phase model encourages the fading of support by requiring that the teacher takeover in the teaching of the activities. In this phase, the STOMP fellow continues to provide the expertise only when necessary. After a 3 – 5 year period, the teachers are thought to have had enough experience to teach the content on their own. As it is in a cognitive apprenticeship, the fellows are responsible for recognizing when scaffolding is needed and when support should be gradually faded out of use.[6]

The third phase of Fitts & Posner's skill acquisition is the autonomous stage, in which learners are fully capable of performing a skill on their own.[4] Anderson calls this stage the procedural stage when applied to the acquisition of a cognitive skill.[3] The procedural stage is achieved when the learner is able to apply their declarative knowledge to solve problems and accomplish tasks.[3] Perfection of a skill is inexhaustible and improvement is always possible even after a person has reached an adequate level of proficiency.[3]

The third phase of the STOMP three-phase model is reached when the teacher has achieved the procedural stage. Teachers who achieve independence in teaching engineering and technology content have the continued use and support of STOMP resources, such as an activity database, to allow for continual improvement after STOMP fellows have been removed from the classroom.

Why Use a Three-Phase Model?

The STOMP three-phase model recognizes that learning a cognitive skill is a gradual process that requires a learner to go through a dynamic process of learning. It is assumed that most K-12 teachers have little knowledge of engineering and technology when embarking in STOMP. Self-efficacy literature shows that a classroom teacher has a better chance of succeeding at teaching a topic if they believe they are capable of teaching this topic.[14] Self-efficacy can be improved when an expert, the STOMP fellow, models their use of knowledge and provides feedback to the learner, or classroom teacher, on their use and application of the knowledge.[12]

According to literature on cognitive skill acquisition, to become proficient at applying knowledge, a person must learn content as declarative knowledge and gradually practice using this knowledge until it becomes procedural knowledge.[3] In a STOMP classroom, the classroom teacher begins by learning the content knowledge from afar. As the teacher learns the facts and procedures involved in engineering and technology, they are expected to begin applying this knowledge in their own teaching. The process of converting declarative knowledge into procedural knowledge requires time and support from a STOMP fellow.

Many classroom teachers do not have experience in applying engineering and technology content in their teaching. As teachers are expected to be proficient in many different areas, it is important that the knowledge they have be applicable in the context of teaching. The purpose of STOMP as a cognitive apprenticeship is to provide teachers with the opportunity to learn and use engineering and technology content in the context that they are required to use it. The role of the STOMP fellow is to model, coach, provide scaffolding, and then fade their support as the teacher reaches proficiency in using their newly acquired cognitive skill. Through a three-phase model, STOMP can sustainably impact classrooms by empowering teachers to become independent in teaching STEM content.

Other STEM Outreach Programs with an Apprenticeship Model

Due to greater pressure put on teachers to teach STEM content, the National Academy of Sciences, The National Academy of Engineering, and the Institute of Medicine have recommended that universities increase their role in K-12 education.[16] Several STEM outreach programs with goals similar to STOMP have been established at various institutions across the United States. Few studies have analyzed the impact of these programs on teachers.

At the Colorado School of Mines, a study was conducted on their outreach programs (EOW, EMSC, PSMM, and GK-12), which target the improvement of K-12 teacher knowledge and understanding of mathematics and science through partnerships with STEM experts – graduate students or faculty members.[16] The study found that teachers enrolled in these programs valued the hands-on component, were encouraged by the program to use technology at greater frequencies in their classrooms, and appreciated the in-class content support. An assessment of teacher knowledge using pre- and post-tests identified a statistically significant increase in teacher performance indicating that these outreach programs were having a positive impact on these teachers' content knowledge.

At the University of South Carolina, a study was conducted looking at teachers enrolled in their GK-12 program; an NSF initiative that partners graduate student "experts" with K-12 teachers. The study found that teachers who were enrolled in the program reported that the hands-on aspect of the program was important in helping them apply science and math principles.[17]

A similar study was conducted on Project STEP at the University of Cincinnati, which partners undergraduate and graduate students with middle and high school teachers.[18] This study found that teachers reported Project STEP as important to them for content support, especially for keeping them up-to-date on current technology trends.[18] These teachers also noted that being enrolled in the program was a motivator for them to teach and learn STEM content.[18]

These studies have shown that programs similar to STOMP have had a positive impact on the participating K-12 teachers.

Research Methodologies

The sample size obtained for this study was thirteen teachers currently enrolled in STOMP. The sample consisted of teachers at all three phases of the STOMP model. To measure teacher reactions to STOMP, a three-part survey was developed (see Appendix) looking at teachers' reasons for hosting STOMP fellows, teachers' beliefs in the importance of teaching engineering and technology, and teachers' confidence in teaching and understanding of engineering and technology content.

The first part of the survey asked teachers to report on their perceptions of STOMP. Questions are asked that gauge the amount of time they have participated in the program and what aspects of STOMP are most useful to them. These questions were designed to identify whether teachers believe STOMP is a source of material or pedagogical content support.

The second part of the survey asked teachers if they believe that learning engineering and technology content is important for themselves and for their students. This section is designed to evaluate whether or not teachers believe that learning this content is important, which may indicate their willingness to learn this content.

The last part of the survey asked teachers to rate their confidence and ability to teach. Understanding a teacher's confidence in their general teaching is a good baseline to compare how teachers rate their confidence in teaching engineering and technology content before and after participation in STOMP. The engineering and technology questions are designed to evaluate the teacher's domain specific self-efficacy, even for teachers with high self-efficacy in teaching in general. Additionally we asked teachers if they believe that their understanding of engineering and technology content has improved through their participation in STOMP.

Results & Discussion

Results from the thirteen teachers indicate that teachers have a positive view of STOMP based on a belief that it benefits them through the provision of content support in engineering and technology. Teachers rated the importance of STOMP as a resource for engineering and technology content as high (4.83 out of 5). Teachers also rated the importance of learning this content through STOMP as high (4.18 out of 5).

We looked at how teachers rated the importance of the resources provided by STOMP - *extra help in the classroom, support in engineering and technology content, the fellows as role models to the students, and the access to equipment*. On average, the teachers rated all of these as being important. Having extra people in the classroom to help out was rated the lowest on average (3.89 out of 5), and having support in engineering and technology content was rated the highest on average (4.83 out of 5). Table 1 shows the average rating of importance of resources provided by STOMP. Results from Table 1 show that teachers believe that STOMP is an important resource in terms of engineering and technology content support.

Looking beyond resources, we then analyzed how teachers rate the importance of STOMP for learning engineering and technology content for themselves and for their students. Teachers rated the importance of STOMP for learning engineering and technology content high for both students (4.77 out of 5) and teachers (4.18 out of 5). This indicates that teachers value learning about engineering and technology content from STOMP fellows and feel that it has an important impact on their students' learning of this content.

Table 1. Teachers' Reasons for Hosting STOMP

Reasons for Hosting STOMP in Your Classroom	**Average Rating of Importance (0 – 5 scale)**
Support in Engineering and Technology Content	4.83
Access to Equipment	4.58
Young Role Models	4.42
Extra Hands	3.85

Finally, we looked at how teachers rated their confidence in their ability to teach in general, and their understanding of and ability to teach engineering and technology content before and after participation in STOMP. Figure 1 shows the results from this question. On average, teachers rated their confidence in their ability to teach generally as being very high (4.85 out of 5); however, on average, teachers rated their confidence in their ability to teach engineering and technology content as 2.47 points lower (2.38 out of 5) than their confidence in teaching in general. This shows that domain specific self-efficacy may affect these teachers' desire and motivation to teach these topics. Teachers' low confidence in their ability to teach engineering and technology content is most likely due to the low rating of their understanding of technology and engineering content (2.64 out of 5). This shows the need for a program that can effectively empower teachers with the knowledge they need to confidently teach engineering and technology content.

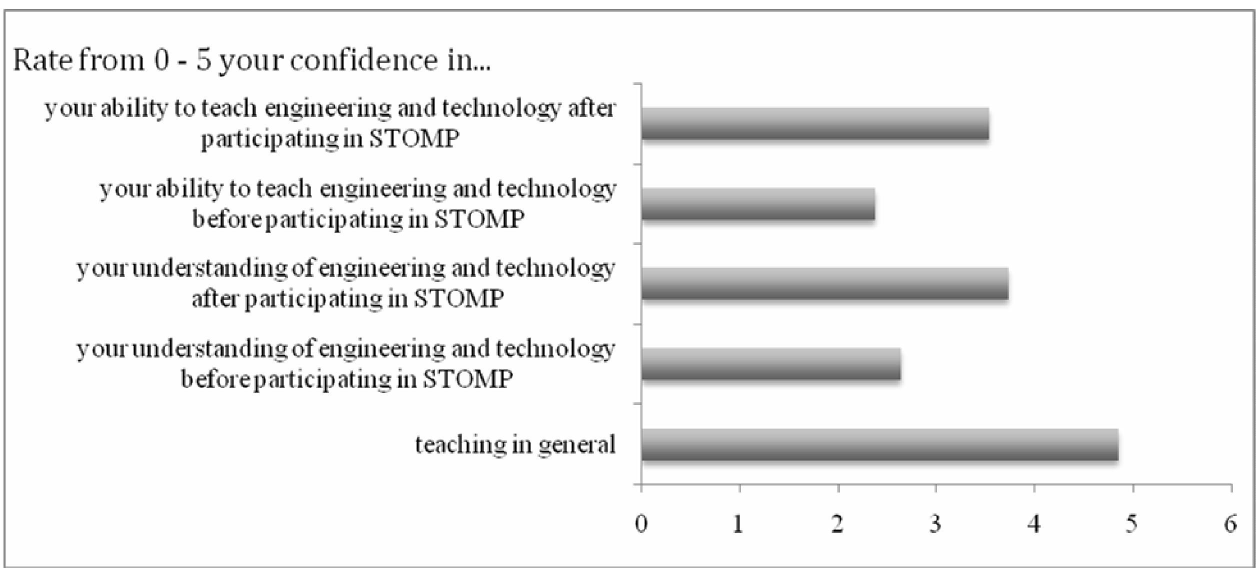

Figure 1. Teacher Confidence

Overall, the results show that after participation in STOMP, classroom teachers feel that their understanding of and ability to teach engineering and technology content increased. Average rating of understanding of engineering and technology content increased by 1.09 points (on a scale from 0 – 5). Teachers' average rating of their ability to teach engineering and technology content increased as well by 1.16 (on a scale from 0 – 5). These results show that teachers feel that STOMP has empowered them with the knowledge they need to teach engineering and technology content in their classrooms.

Conclusion & Future Considerations

The implementation of a three-phase model in STOMP will increase the sustainability of the program by providing teachers with the training and support to become independent in teaching engineering and technology content. Our results show that STOMP is useful in that it increases a teacher's self-efficacy in their abilities to teach engineering and technology. Teachers also reported an increase in their ability to teach, and knowledge of, technology and engineering content. We feel that we will reach more K-12 students and teachers by limiting the amount of time each teacher participates in the program. However, it is important that teachers leave the program with the interest, confidence, and knowledge to be able to implement STEM curriculum on their own.

Extensions of this study should include a larger sample of teachers with a greater variety of STOMP experience. Although teachers in this study were surveyed on their length of participation in STOMP, the majority of teachers who responded were in their first or second year. Our sample size limited our ability to compare length of participation with teacher confidence or understanding of engineering and technology content. Collecting information pertaining to the technical backgrounds of the STOMP teachers would also enhance the analysis on the impact of STOMP. A comparison with non-STOMP teachers would also supply additional insight into the impacts of STOMP. Although this study did not compare teachers enrolled in STOMP to their peers, it should be noted that most of the teachers reported initiating their involvement in STOMP themselves based on their perceived lack of confidence with, or knowledge of engineering and technology content. This was supported by teacher statements like:

> *"I did not feel as confident in teaching engineering and technology as other science topics. My coworker suggested contacting you."*

> *"…we are supposed to teach engineering concepts according to my school district, but we have been given hardly any training!!"*

A comparison group would provide deeper insight into the impacts of STOMP.

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Appendix: Teacher Survey

1. How many semesters have you participated in STOMP?

2. Rate from 0-5 (0 being not important and 5 being extremely important) the importance to you of the following reasons for hosting STOMP fellows in your classroom.
    a. extra hands
    b. support in engineering/technology content
    c. young role models for students
    d. access to equipment

3. Rate from 0-5 the importance of learning engineering and technology through STOMP
    a. for you as the teacher
    b. for the students

4. Rate from 0-5 (0 being not very confident, 5 being very confident) your confidence in:
    a. teaching in general
    b. your understanding of engineering and technology before participating in STOMP
    c. your understanding of engineering and technology after participating in STOMP
    d. your ability tot each engineering and technology before participating in STOMP
    e. your ability to teach engineering and technology after participating in STOMP

5. Where did your initial interest in participating in STOMP come from?