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Studying In-service Teacher Professional Development on Purposeful Integration of Engineering into K-12 STEM Teaching (Research to Practice)

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Abstract

Integrated STEM approaches in K-12 science and math instruction can be more engaging and meaningful for students and often meet the curriculum content and practice goals better than single-subject lessons. Engineering, as a key component of STEM education, offers hands-on, designed-based, problem solving activities to drive student interest and confidence in STEM overall. However, K-12 STEM teachers may not feel equipped to implement engineering practices and may even experience anxiety about trying them out in their classrooms without the added support of professional development and professional learning communities.

To address these concerns and support engineering integration, this research study examined the experiences of 18 teachers in one professional development program dedicated to STEM integration and engineering pedagogy for K-12 classrooms. This professional development program positioned the importance of the inclusion of engineering content and encouraged teachers to explore community-based, collaborative activities that identified and spoke to societal needs and social impacts through engineering integration. Data collected from two of the courses in this project, *Enhancing Mathematics with STEM* and *Engineering in the K-12 Classroom*, included participant reflections, focus groups, microteaching lesson plans, and field notes. Through a case study approach and grounded theory analysis, themes of self-efficacy, active learning supports, and social justice teaching emerged. The following discussion on teachers' engineering and STEM self-efficacy, teachers' integration of engineering to address societal needs and social impacts, and teachers' development in engineering education through hands-on activities, provides better understanding of engineering education professional development for K-12 STEM teachers.

Key words: STEM integration, precollege engineering education, professional development, STEM teacher self-efficacy

Introduction

Education policy and reform have placed a major emphasis on STEM college and career readiness for national economic success [1]-[3]. Integrated STEM approaches in K-12 science and math instruction can be more engaging and meaningful for students and often meet the curriculum content and practice goals better than single-subject lessons. In addition, student engagement and motivation increase in math and science classrooms when there is an increased focus on engineering approaches such as defining problems, designing solutions, and hands-on activities [4]. Critical to successful implementation of STEM approaches, is the direct focus on and engagement with engineering as a way for understanding and creating in the world [4].

However, studies show that while K-12 science and math teachers believe that implementing engineering practices in their classrooms is important, they do not feel familiar with or supported enough to actually do so and may even exhibit anxiety toward the subject [5]-[8]. Even as national standards, such as the Next Generation Science Standards (NGSS), place an emphasis on integrating engineering practices into science teaching, there is still a persistent concern for supporting in-service K-12 teachers to develop and embed rigorous engineering instruction into their practice [9]-[12]. Furthermore, there is a critical need for more role models for all students, especially underrepresented minorities (URM) and those in high-need school districts, in STEM education and career fields [13]. While teachers can help fulfill these roles for students in STEM, more attention is needed on professional development supports for teachers and leaders in STEM education and teacher education [13].

To address these needs and the increased focus on engineering integration, this research study examines the supports provided by one professional development program that served K-12 teachers in their development as STEM teachers with a focus on engineering integration. The professional development program studied here positioned the importance of the inclusion of engineering content into multisubject elementary classrooms and science and math middle and high school classes to drive engagement and interest of all students in high-needs schools as a motivation for teachers' development of STEM lessons.

This study looks at two specific courses within a STEM professional development program, *Enhancing Mathematics with STEM* and *Engineering in the K-12 Classroom*, to explore how they support K-12 teacher development of and implementation of engineering practices in their planning. The data collection, analysis, and findings discussed in this paper are situated within the contexts of professional development, self-efficacy, engineering in the classroom, and social justice. The following discussion on teachers' engineering and STEM self-efficacy, teachers' integration of engineering to address societal needs and social impacts, and teachers' development in engineering education through hands-on activities, provides better understanding of engineering education professional development for K-12 STEM teachers.

Context (Literature Review and Prior Work)

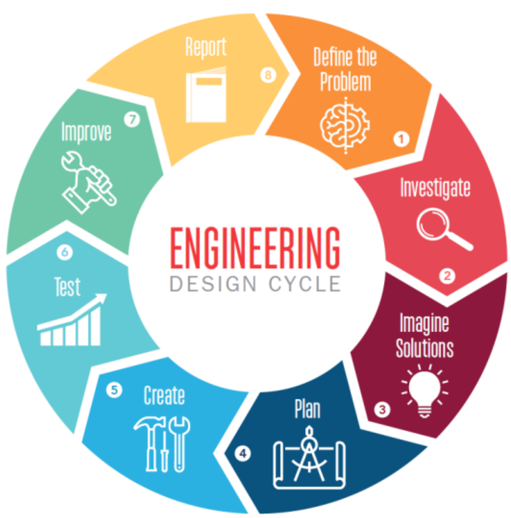
This work is framed by the facts that engineering and STEM education should be part of all students' education, effective professional development can be used to increase engineering integration in STEM education, and that self-efficacy can be used as a lens for growth and change in K-12 STEM teachers [14]-[16].

STEM as social justice

Sustained emphasis on STEM education as a means for global competition places significant pressure on educators to promote science and math curriculum in their classrooms [2],[3]. Recent policies for STEM education reform aim for "lifelong access to high-quality STEM education" and for the United States to be "the global leader in STEM literacy, innovation, and employment" [17]. These aims require us to provide college- and career-readiness, quality STEM instruction, and accessibility to technology as a civil right for all STEM students [16]. Through a social justice perspective, we can use engineering as an instrument for informed citizenship, action and agency, critical thinking in our communities and in STEM fields overall [16], [18], [19].

The engineering design process offers teachers a way to integrate engineering concepts and diverse ways of thinking through plain language and engaging activities. This iterative cycle of questioning, imagining, planning, creating, and improving pushes students and teachers to problematize their surroundings and to design solutions for common good [20], [21]. Figure 1 depicts the Engineering Design Cycle that we share with teachers and teacher candidates.

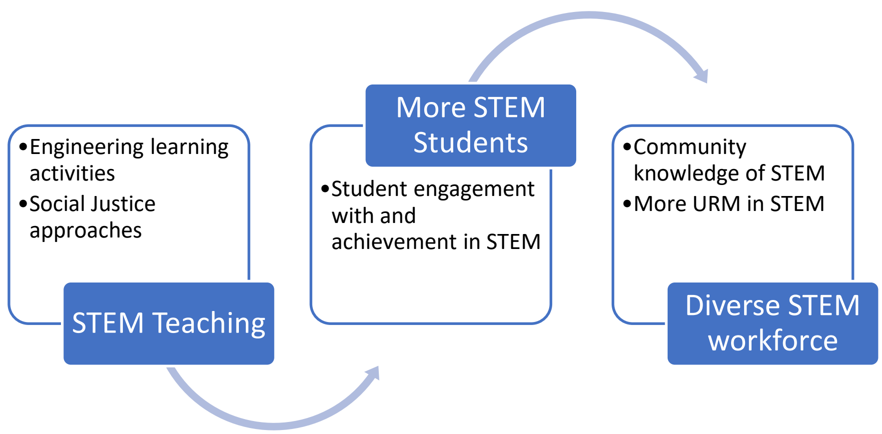
Figure 1. *Engineering Design Cycle*



The engineering design process supports students' and teachers' access to critical thinking strategies for sustainability problems, ecological issues, and community-based concerns [21]-[23]. As students engage in the cycle, they encounter problems that are navigated by using personal experiences, content knowledge from other subjects and interpersonal skills. Community-based or sustainability-based engineering design challenges are rich in moments for valuing student voice, community cultural wealth, and agency in STEM education [22]-[25].

Integrating engineering into science and math content classrooms can deepen students' understanding of the content, connection with STEM disciplines, and STEM literacy. For instance, students can dive deeper into STEM concepts by designing solutions for real-world concerns through bioengineering or by focusing on community planning [26], [27]. Engineering and STEM integration inherently engage students in culturally relevant pedagogy by pushing them to think critically about their community and political action while working towards STEM literacy and achievement [16], [19]. We can use STEM education to acknowledge community issues, promote awareness, and generate reflection in the classroom [27]-[29]. By pushing for engineering design practices that leverage student experiences and engage them in critical work on real-world STEM problems, we provide a space for meaningful, justice-based STEM education. We show how this approach has the potential for change in the following Figure 2.

Figure 2. *Importance of STEM Teaching for Society*



Professional development and previous work

Darling-Hammond and Richardson [29] find the most effective PD experiences for teachers are prolonged; promote insight into student learning; involve collaboration with other teachers; develop content understanding through hands-on work; and provide opportunities for classroom application. Further, strong PD models are deeply embedded in subject matter (in this case, math and science); designed to involve active learning; able to connect teachers to their own practice (accomplished through lesson development and reflection); and part of a coherent system of support (provided through courses and personal relationships with PD instructors and faculty) [31]-[33]. This design allows teachers to develop pedagogical content knowledge (PCK) in STEM as they improve integration of STEM subjects, increase content knowledge in math and science, and engage in engineering design applicable to K-12 settings—with connections to math and science standards. Professional development opportunities are available to in-service teachers as workshops, conferences, college courses, or professional learning communities.

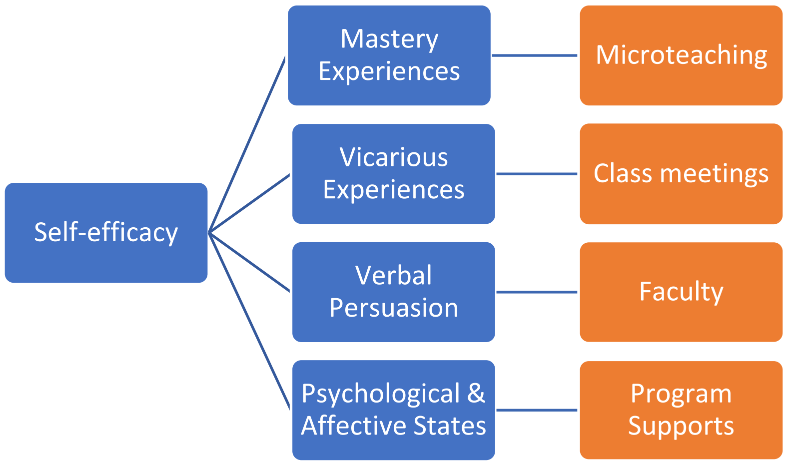
Professional learning communities (PLCs) are groups of people that collaborate to develop their knowledge and expertise of a common interest or passion by sharing individual resources and by engaging in critical dialogue [34]. Hord's [35] commonly used definition describes educational PLCs as a community of "Five Dimensions". These are 1) supportive, shared leadership, 2) collaborative learning with a student needs focus, 3) shared vision and values focused on student learning, 4) supportive structural and interpersonal conditions, and 5) shared practice [35], [36]. Furthermore, in STEM education PLCs, vertical alignment among teachers provides an added layer of support to increase understanding of STEM content, provide opportunity for individual professional growth, and build consensus across grade levels and subject areas [15].

The two STEM pedagogy courses that anchor this study were designed with these best practices of professional development in mind. Additionally, they were connected back to our prior studies on engineering education for preservice teachers and implementing STEM professional development in vertically aligned PLCs [15], [37]. These elements of the courses offered insight into STEM teacher self-efficacy in engineering and also revealed opportunities for increased STEM teacher agency and growth through hands-on activities.

<u>Self-efficacy as a framework for analyzing participants' experiences and development</u>

We selected Bandura's [14] self-efficacy framework as a lens to examine participants' development and growth during the two courses that comprise this study. Bandura's work is rooted in psychology and has been widely applied, including to education contexts [38]-[43]. It is useful as a framework because self-efficacy is an individual's own perspective of their future ability to perform a given task. In this case, participants self-efficacy for planning engineering and STEM learning experiences for their students were examined. Bandura's framework explains that self-efficacy can be developed through four modes. The first, mastery experiences, is when an individual has the opportunity to try out the given task, often with guidance or a scaffolded experience [14]. Each mastery experience has the potential to support the person's development in self-efficacy for the task, particularly when successful [14]. The second mode we consider is vicarious experiences. Vicarious experiences are those reported by peers or others that can be thought of as similar to the individual in some ways [14]. Learning of successful experiences of others provides encouragement for the individual to develop self-efficacy that their attempt will be successful, as well [14]. Verbal persuasion can be connected to vicarious experiences when there is encouragement from trusted others to carry out the task at hand and that the person will be successful [14]. However, it is generally described as a mentor or trusted individual providing this push to achieve. Finally, psychological and affective states speak to the stress or personal anxiety that can be connected to performing the task [14]. This concern can be mitigated in varied ways, depending on the task, but in this study, participants were all part of programs at the college that provided social connections to other participants and instructors, and was created to be supportive and welcoming in general. Figure 3 maps experiences in the study in the two courses to the four modes of Bandura's theory.

Figure 3. *Mapping Course Experiences to Bandura's Self Efficacy*



Methods

This study uses a qualitative case study approach to examine how in-service teachers designed integrated STEM lesson plans, developed their practice in the context of social justice, and increased pedagogical content knowledge (PCK) of engineering in the science or math contexts. Here, case study analysis allowed us to capture the nuanced experiences, changes, and struggles that the teachers encountered throughout their time in two courses, *Enhancing Mathematics with STEM* and *Engineering in the K-12 Classroom*, through rich, detailed data and analysis [44]. Using a narrative case study approach allowed us to develop a detailed story based on our interpretations of the data and our co-constructed understandings with participants and our research team [45]. It was important that we pursue a qualitative research methodological approach to understand subtle changes that occurred throughout the participating teachers' experiences in the professional development. These subtle changes cannot be addressed with the same level of detail through quantitative approaches. Rather, they require a constructivist qualitative approach to collaboratively explore the participants' writing, conversations, teaching, and instructional planning [46].

Data collected includes participant reflections, coursework, instructor observations and reflections, focus groups, and lesson plans. These data sources, described in detail below, offered descriptive insight into the stories of these science and math teachers. This study was driven by the research question: How do STEM-focused pedagogy courses support teacher development of and implementation of engineering practices in their planning?

Participants & setting

Our research team worked with 18 teachers in elementary and secondary science, math, or computer science settings from two federal grant-funded programs in STEM education and leadership. All participants applied for spots in one of the two grant-funded programs and, therefore, were aware of these programs' commitment to STEM integration and social justice impetus. Of the 18 participants, 15 identified as underrepresented minorities in STEM including women and teachers of color, one participant declined to identify, and 6 were elementary school teachers. The participating teachers had a range of experience in teaching at different grade levels K-12. Of the 18 participants, one was in their first year of teaching, three had less than 5 years of teaching experience, five had 5-10 years of teaching experience, five had 11-20 years of teaching experience, and four had more than 20 years of teaching experience. All of the teachers were working in local, urban or suburban, high-need school districts. Tables 1 and 2 further detail participants' gender, race/ethnicity, subject area, grade level, and teaching experience.

Table 1. *Participant Details*

	Elementary	MS Science	MS Math	HS Math	HS Science	HS Computer Science
Female	6	3	1	2	2	1
Male	0	1	0	2	0	0

Table 2. *Additional Participant Details*

	Black or African American	Hispanic or Latinx	White (not Hispanic)	Multiple Races	Not identified
Female	2	4	7	1	1
Male	0	0	2	0	1

This study is embedded in the broader context of a larger six-year study on STEM teacher leadership. The case chosen for this study included two courses that all 18 teachers completed at the time of this study called, *Enhancing Mathematics with STEM* and *Engineering in the K-12 Classroom.* As part of the federally-funded Noyce Master Teacher track IV grant, participants experienced the two courses as part of their professional development. These courses make up one-third of an Advanced Certificate in STEM Education at the college, which is a specialization for practicing teachers offered by New York State. In addition, four of our Noyce Scholar track I graduates, who were already teaching, participated in these courses and the study. Both courses were taught by School of Education faculty, who helped develop the Advanced Certificate and, one of whom, is the PI of the Master Teacher initiative.

These courses both centered on social justice-based STEM teaching and STEM integration with a specific focus on promoting teacher agency in the STEM classroom. *Enhancing Mathematics* centered mathematics pedagogy as an instrument for integrating STEM in all content areas. In this course, the students considered how mathematics can be STEM-focused and how mathematics be used as a lens for science and engineering practices in a variety of lessons [47]-[49]. *Engineering in the K-12 Classroom* connected engineering closely with society and highlighted engineering fields, careers, approaches through readings, hands-on engineering activities, and vertically aligned grouping [4], [50], [51]. This course also supported teachers making connections to other content areas, specifically math and science, but also English language arts and social studies, particularly at the elementary level, in their lessons. To support the robust inclusion of engineering approaches, the program employed a partnership with a local school of engineering and invited engineering and STEM faculty to be guest speakers during each semester on engineering topics (Table 3, below). Here, students worked through engineering-focused lessons that enrich students' STEM engagement through hands-on activities and the engineering design process [5], [20], [21], [52]-[54].

Table 3 illustrates the invited guest speakers and the topics covered in each course. It also outlines the data collected in each semester.

Table 3. *Enhancing Math and Engineering Course Descriptions*

Semester	Courses	Guest Speakers and Topics	Data Collected
Spring 2019 Fall 2019	Enhancing Mathematics with STEM	Environmental Educator – Environmental education and connections to engineering applications Education Faculty – Using engineering activities with students Math Faculty – Teaching diverse learners Engineering Faculty – Robotics	STEM autobiography, lesson plans, reflections, microteaching, questionnaires, focus group
Fall 2019 Spring 2020	Engineering for the K-12 Classroom	Math Faculty – Modeling Chemical Engineer – systems engineering Engineering Faculty – Engineering outreach program for HS students Biology Professor – bioengineering and Green Fluorescent Protein; bioengineering and COVID vaccine	Engineering autobiography, lesson plans, microteaching, reflections, questionnaires, focus group, observation of classroom teaching (Fall only)

Using our analysis of the data collected in each of these courses, we present findings from the results of two years of a mixed-methods study and seek to illuminate themes of: a) teachers' increased self-efficacy for teaching engineering, b) active learning supports learning how to teach STEM, and; c) rooting societal needs and social impacts in engineering education.

Data sources

The following triangulated data sources were collected as part of the routine procedures of both the *Enhancing Math* and *Engineering* courses or as part of the requirements of their grant-funded programs. These data sources reflect the multifaceted approach that we took to better understand the whole picture of STEM integration in these participating teachers' work.

Reflections. At the beginning of the semester in each course, participants were asked to write a STEM/engineering autobiography and, at the end of the semester in each course, participants were asked to write a reflective essay about their experiences in the course and their new understandings of STEM education. These reflections not only shed light on the experiences that the teachers had in both courses, but they also provided a space for the participating teachers to think deeply about their growth in their practices that occurred between both courses [55], [56].

Coursework. For each course, the teachers were asked to design integrated STEM microteaching lesson plans using the 5E lesson plan model. These lesson plans were shared with us for analysis. In addition, the engineering unit plan assignment and microteaching in the engineering course were included in the data set.

Focus groups. At the end of each course, the teachers engaged in focus groups that generated conversations on their coursework, pedagogy, and STEM agency. The teachers shared their thoughts, experiences, and reflections in conversation with each other.

Field notes. Faculty and the research team documented their experiences and thoughts as they engaged in the two courses in this study. Faculty and research team members debriefed routinely to discuss the courses and each member kept records of these meetings as well.

Data analysis

We used a narrative case study analytical perspective to interpret the writing, observations, and conversations that we collected for this study [44]. This analysis approach allowed us to read the participating teachers' reflections and coursework with a detailed focus on their experiences, stories, and introspections across their personal and practitioner documents. Furthermore, this allowed us to view their observations and listen to their conversations with the necessary openness for considering their individual and group achievements, changes, and struggles.

Borrowing from components of the constructivist grounded theory analytical approach, all data sources were reviewed by each member of the research team [45], [46]. This analytical approach enabled us to co-construct findings with the participating teachers and position the participants as researchers in the study [46]. In initial rounds of analysis, the team read over all data sources and created general summaries of the sources in their individual notes. In the second round of analysis, the team left comments on shared digital copies of the data sources in a collaborative approach to open coding [45], [46]. In the third round, researchers summarized their understandings of the generated codes and collaborative notes [44], [46] Throughout the final stages of analysis, the team reviewed collective comments to categorize codes and consider overarching themes [44], [46]. These themes resulted in the findings described below.

Triangulation and rigor were ensured through the use of varied data sources that captured written, spoken, and performed moments in the process of professional development through the two courses [44]. Rigor was further established through prolonged engagement with the participants which allowed for continuous conversations, member checking, and peer debriefing along the process of analysis and writing [45]. This participatory research approach amplified the participating teachers' voices and created the space for an iterative process of reflection, writing, and rewriting among the whole team [44], [46].

Results

The findings presented here are organized into themes illustrating the supports that two STEM pedagogy courses provided to practicing teachers in their development towards increased focus on engineering in their teaching and incorporation of STEM. These three themes illustrate the learning environment, work in which teachers engaged, and how they developed.
Together, these categories of findings demonstrate the growth that practicing STEM teachers experienced in developing engineering-centered, integrated STEM pedagogy.

<u>Theme one: Teachers' increased self-efficacy for teaching engineering</u>

Using Bandura's [14] framework for developing self-efficacy, we examined participants' work in the two graduate courses, including autobiography assignments, final reflections, and lesson and unit planning assignments. We also debriefed the faculty who taught these courses for their reflections and observations. We connected these varied data sources to the focus group videos and transcripts to create a picture to describe how teachers were able to grow in their feelings of being able to teach engineering and STEM. These findings were made across the K-12 group, with the majority of teachers indicating less self-efficacy for teaching STEM at the outset of the study. Of the 18 participants, three consistently reported high levels of self-efficacy and confidence for implementing STEM and engineering lessons with students at each data collection point. The rest of the group had lower, varied levels of reported comfort and ability for teaching engineering. Interestingly, despite the fact that two of these teachers had taken courses in engineering courses as undergraduates, they independently shared that learning how to be an engineer does not translate into knowing how to support students' work using engineering practices. For example, this high school teacher shared in her "Engineering Autobiography" assignment:

> Regarding engineering, I must honestly say this is the area in which I am the least confident as a teacher. I feel that I am able to successfully design STEM lessons that are based in science, technology, and mathematics but I struggle to incorporate the engineering part. (Fall 2019)

Her experience in an engineering program for high school students when she was younger and taking engineering courses in college did not support her work now as a teacher, and she was not alone. The 15 participants who did not consistently report high levels of self-efficacy shared the experience of not knowing how to use engineering or create STEM lessons in the classroom to varying degrees. Some shared some forays into engineering projects, but with a lack of confidence related to them or feeling that they could do it better. Some made statements such as "Overall, I do not feel confident as both student and teacher when it comes to engineering" (Engineering Autobiography, elementary teacher, Fall 2019) or indicated that they were nervous about doing so or had much to learn. Several noted in the engineering course that they did not realize they were employing the engineering design cycle in at-home projects in their lives outside of the classroom. Similarly, two participants who had undergraduate coursework in engineering shared growth in how to teach engineering, explaining that just because you know what engineers do, does not mean you know how to engage students in the process. Notably, one of these two teachers explained that teachers need a different type of understanding of engineering – just enough to get students excited and engaged in the engineering design process – not as much as you need to *be* an engineer. By the end of the first course, participants were sharing that their confidence for STEM teaching had grown and this was illustrated in their lesson planning assignments for the course. In one end of semester reflection, a high school teacher shared:

> Now that I am gaining a deeper understanding about STEM education, I realize that I have been incorporating engineering into my classroom. I would say that my level of comfort and my confidence as a teacher of STEM is improving. I am seeing so many positive outcomes from my students by implementing these lessons. I am excited to keep learning and growing as a STEM educator as I move forward in this program. (Spring 2019)

At this point, other teachers shared they appreciated working with peers in the course to develop STEM lessons, an especially difficult task for some veteran teachers who were not required to create formal lesson write-ups for their school district. A high school teacher shared how the siloed nature of the high school subjects never provided an opportunity to incorporate other subjects and that this approach was both engaging and beneficial for students.

By the end of the second course, all participants shared strong self-efficacy for teaching STEM and engineering lessons. In addition, three participants specifically mentioned that the experiences in these courses have given them confidence to speak up as STEM teachers to administrators and colleagues. A middle school teacher shared how she previously felt alone, trying to implement project-based learning with students and that she was not sure if what she was doing was right: “I used to be the crazy lady upstairs…now I can say, ‘Yes, I am a STEM teacher! Now it is acceptable and ok and now that the standards are changing” (focus group, Fall 2019).

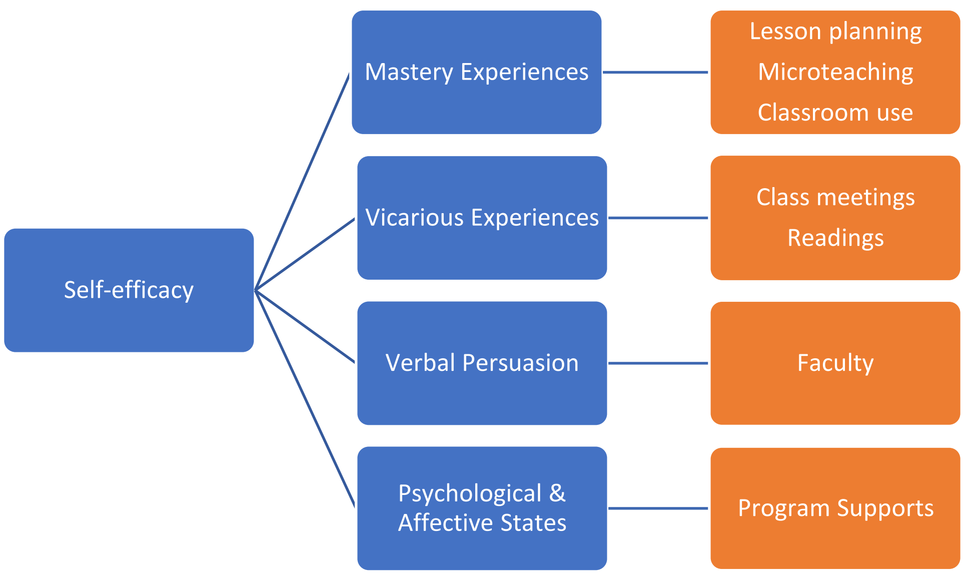
The growth of participants’ self-efficacy is a dramatic shift in two semesters’ time. Their development was evidenced through their work in the second course, which focused on utilizing the engineering design process with students, successfully leading an engineering design activity with others, and planning an interdisciplinary mini-unit that utilized engineering as a meaningful part of the learning activities. The instructor for the course was impressed with these products and how engaging they would be for students. Further, several teachers took the initiative to implement activities immediately with their students. While researchers were unable to observe these lessons, the course instructors reporting of teachers’ descriptions in class were included in our data. Examples of learning activities planned by participants include connecting engineering design with social studies units in elementary grades; using COVID-19 data to drive a math lesson on statistics that culminated in designing and creating masks; and using a systems engineering approach for bus routes that connected to geometry. These engaging projects are just a few examples of what participants presented in class and many went on to try with their students. The course instructor was “thrilled” with the teachers’ work and applications to their teaching area and classrooms (instructor reflection, Spring 2020). In the final focus group and course reflections, teachers shared how they felt more comfortable implementing engineering in their classrooms and planning for engineering projects with students. Perhaps illustrating an even higher-level of self-efficacy for teaching engineering, several teachers explained how these instructional approaches supports students’ learning for life:

> I always tell colleagues that in addition to increasing student interest and engagement, teaching engineering makes it more fun and exciting to be a teacher because you get to teach “real-life” lessons and your instruction feels significantly more impactful”. (high school teacher, focus group, Spring 2020)

Another teacher described how when students say that they “want to help people” they only think about becoming doctors or the medical field, but now she can share that engineers do this as well, they solve problems for society, which she came to understand through the engineering course (focus group, Fall 2019).

While it is not unexpected that teachers would gain confidence for teaching engineering after participating in two STEM-based courses, it is important to understand how their development took shape and the supports that were most useful. Although the courses were purposefully designed to support teacher growth in STEM teaching, certain aspects emerged as more important than previously considered, as participants specifically cited them as being notable supports. Figure 4 is a revision of Figure 3 to incorporate additional supports cited by participants that supported their work and aligned to the self-efficacy framework. Through focus group interviews and end-of-course reflections, teachers shared the supports that were most valuable for their growth. We describe this in more detail in Theme Two, but it is relevant to Theme One, as these contributed to their self-efficacy development.

Figure 4. *Revised Mapping Course Experiences to Bandura's Self Efficacy*



<u>Theme Two: Active learning supports learning how to teach STEM</u>

Participants in this study each grew in their comfort and ability to plan and implement STEM lessons during the two courses. It is important to note that specific learning activities embedded within the courses were successful towards this goal. While the course meeting activities included varied, common graduate-level instructional strategies, such as course readings, short lectures, discussions, group work, and lesson and unit planning assignments, additional activities designed to specifically support STEM pedagogy were also a main part of the experiences. In addition, using our previous work on Vertical Professional Learning Communities, this approach was incorporated with a lesson study aspect, which has previously been impactful for in-service teachers [15]. This work is a combination of active learning through collaboration and discussion of planning, as well as the active engagement with hands-on materials teachers participated in through groupwork guided investigations.

This work in these two courses provided contexts for teachers to explore teaching in new ways, or to examine their existing teaching practices with new frameworks, while working with peers. Some of these frameworks were provided through course readings, mini-lectures and modeling during class meetings, but some were co-constructed by teachers as they worked together on planning and provided feedback to one another on microteaching. We can align these experiences with social constructivism and participants learning through working with one another. Similarly, the high school teacher that had previous engineering experience shared that she felt that she had discovered that she is in fact a STEM teacher and that the experiences provided her the support she needed to recognize that.

In the first course, teachers worked together to plan STEM lesson plans vertically – working together on a particular content topic, but geared for each of their grade levels. This was a major course experience that many participants talked about in their reflections and the focus group as an important part of their work. At first, the course instructor noted the resistance to planning this way, however, by the end of the project, the teachers appreciated learning from one another in this type of grouping that many had not experienced before. An elementary teacher shared how the process helped her realize that she is already doing STEM integration, but did not have the lens to see her practice that way prior to this work. Another elementary teacher explained how this course helped open up her mind to engineering learning that engineers are problem solvers.

Another significant piece of the industry in this course that was met with initial resistance was the microteaching of an engineering design lesson in the second course. Although teachers participated in several hands-on engineering design group projects in the engineering class including creating a version of an aeolipile – Hero’s engine and balloon cars, for example, designing their own seemed intimidating. Research shows the microteaching process is a powerful experience for teachers [40], [57], [58]. In this course, teachers designed a 5E lesson with a requirement the “explore” piece be an engineering design activity [59]. In class, teachers explained the lesson overview and then presented the hands-on explore piece of the activity with the class. During COVID restrictions, this microteaching was done at home, with a family member or friend and was recorded. In both cases, teachers in the class either participated in the activity or viewed the video and then were asked to provide both warm and cool feedback to their peers. This type of structured feedback has been used in other professional development models led by the research team with success [15], [47], [60]. After the presentation and feedback, teachers wrote a reflection on the experience. Teachers reported this cycle of planning, presentation, feedback and reflection was beneficial in developing their skills for planning and carrying out engineering design projects.

Theme Three: Rooting societal needs and social impacts in engineering education

Throughout both the *Enhancing Math* and *Engineering* courses, there was a heavy emphasis on equity, multicultural approaches, societal needs, and social impacts in STEM education. In the *Enhancing Math* course, teachers engaged in reflections and discussions on issues of social justice and social action in teaching. In the first course, a unit was spent unpacking the current state of under-represented minorities in science and engineering degrees and careers through data-driven group work in class using federal statistics. This was paired with readings to push teachers to reflect on their own experiences, such as, *White Privilege: Unpacking the Invisible Backpack* [61]. Class discussion and revelations of personal experiences made this unit exploration powerful and meaningful for teachers, as evidenced through their reflections in their assignments and the instructor's observations and reflections.

In the engineering course, several themes relating to diversity were addressed, including global explorations of historical engineering achievements, spotlighting the importance of including the work of diverse cultures and perspectives other than Western ones. Connecting the needs of society to the work of engineers was also an important way to emphasize not only that engineering is a human endeavor, but also that it is subject to human biases. The social media initiative *#Ilooklikeanengineer* was also shared with participants as a way to unpack the personal experiences of diverse students in choosing and pursing a degree in engineering. Several profiles were selected from the hashtag collection and teachers discussed the students' experiences in groups with prompts. They shared the profiles they explored with the rest of the class in turn and the whole group discussed. Teachers worked in groups to consider multicultural and sociohistorical approaches to engineering and designed a project focusing on social impacts of engineering. A guest speaker who is an engineer at another institution also visited to discuss community outreach programs for underrepresented minorities in engineering education. These activities supporting conversation and reflection for all the teachers in how they could make a difference in their students' lives by incorporating engineering in their lessons.

Teachers expressed that both the coursework and the social justice perspective in the courses helped them gain a deeper understanding of the importance of STEM education and the need for increased visibility of engineering in content classrooms. A middle school teacher noted that "inclusion and diversity are a student's right and must be advocated for" in his reflection (Spring 2019). A high school teacher was particularly struck by course readings and discussions of race in the classroom. He shared that he now sees it as his responsibility to "fight" repressive stereotypes (Fall 2019). An elementary teacher shared that the guest speakers and readings made her want "to create equity in science" (Fall 2019). These are important feelings for teachers to develop for social justice teaching and for motivation to teach culturally relevant STEM lessons. Students can benefit not only from the content, but from these approaches to support their persistence in STEM. Further, the more teachers that adopt these approaches, it is hoped that other teachers will learn from them.

Implications and Next Steps

The structure of these two courses created an environment in which teachers were able to learn and develop their STEM teaching skills and ability to incorporate engineering in their teaching. Through our analysis we found that the course activities and supports were powerful in pushing teachers outside of their comfort zone into trying new things, reflecting on the experiences, and developing self-efficacy for future implementation. The approaches presented here are important to share with the STEM education community as we collectively seek to help in-service teachers gain the skills to support rigorous STEM learning activities for all students. Examining teachers' self-efficacy development of engineering and STEM teaching was useful to learn if these supports were effective towards the course goals. In addition, we believe the social justice framework provided a powerful impetus for teachers to engage in this transformation and growth, which was supported by the social constructivist nature of the industry in both courses. We posit that the combination of supports for development of self-efficacy and opportunities for collaborative engagement in the context of this work being a social justice endeavor creates a powerful environment for teacher learning.

Teaching engineering is not only now required by many state science standards aligned with the Next Generation Science Standards, but it connects strongly to 21st Century Skills (https://www.battelleforkids.org/networks/p21/frameworks-resources). Teachers in this study clearly found value in engineering design activities for students and for teaching other content areas paired with engineering to drive student interest and engagement. In addition, the analysis of the work presented here has illustrated to the research team that engineering design can be the glue that brings together rigorous STEM lessons and projects. Teachers' planning showed student activities that required creativity, synthesis, and problem solving. These types of learning activities for students are the kinds of STEM work students need, and teachers need to share with one another.

We intend to follow these teachers and conduct future research as they continue in their careers and work on STEM in their classrooms and schools. It will be of interest to the research team and the STEM education community to observe any lasting impacts of teachers' great work in these two courses. The courses continue to be offered at our institution and this research informs their presentation.

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