Board 191: A Model for Engineering Education Professional Development for K-12 Science Teachers

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Abstract

As NGSS has been adopted and implemented across the US, K-12 teachers are tasked with finding ways to incorporate engineering practices in their science lessons, despite having little formal training as part of the teacher certification process. This has led to an increased need for professional development to guide educators to find ways to engage students in engineering practices (such as defining problems, designing solutions and optimizing solutions) while simultaneously learning pure science concepts. While there are grade-level specific and discipline-specific learning standards, there are generic practices and lessons that can be used across grade levels and disciplines. Introducing teachers to the general mind-set of engineers and how engineering practices can help students to apply science concepts is a critical need in professional development for science teachers.

A professional development workshop was conducted over a period of several months during the school year through the Stony Brook University outreach program. Teachers were recruited from a variety of suburban school districts and included teachers at the elementary through high school levels. Participants met at the university and were given time to explore the science and engineering practices in NGSS and the progression of expected student competency from kindergarten through graduation. The workshop engaged teachers in hands-on engineering experiences, included direct instruction on engineering practices and provided time to reflect on ways to incorporate these practices in their science classroom. In addition, each participant was required to complete a final project from a list of options provided. Many of the teachers created and instructed new engineering lessons for their classrooms, while being observed by university staff. Several teachers used university-based lessons as a means of providing engineering lessons to their students. Upon completion of the program, a feedback survey was administered, and participants provided overwhelming positive feedback and expressed a desire for further professional development.

Introduction

The Next Generation Science Standards (NGSS) were developed as a way of revolutionizing and improving science education in the United States and initiated educational reforms at local, state, and national levels. The Science and Engineering Practices (SEPs) are one of the three

dimensions addressed in the NGSS and hold equal standing with Cross-Cutting Concepts (CCCs) and Disciplinary Core Ideas (DCIs) as important foundations to student learning. While engineering practices have been embedded and incorporated into the NGSS, science teachers have consistently expressed concerns about a lack of knowledge of engineering practices and the distinction between engineering and scientific inquiry [1]. In addition to the natural science (physical science, earth and space science and life science standards), the NGSS includes standards specific to engineering, technology and applications of science which must be taught, and which can be used to create assessments [2].

As of June of 2023, 48 states have adopted NGSS or NGSS-based science standards [3]. As NGSS has been adopted and implemented across the US, K-12 teachers are tasked with finding ways to incorporate engineering practices in their science lessons, despite having little formal training as part of the teacher certification process. This has led to an increased need for professional development to guide educators to find ways to engage students in engineering practices (such as problem identification, solution design, and optimization) while simultaneously learning pure science concepts. Teachers must receive professional development and education in the core ideas and practices of engineering to be able to shift their pedagogical approach to support their students and develop competency as science educators. While there are grade-level specific and discipline-specific learning standards, there are generic practices and lessons that can be used across grade levels and disciplines. Introducing teachers to the general mind-set of engineers and how engineering practices can help students to apply science concepts is a critical need in professional development for science teachers.

University-based professional development programs for teachers have become increasingly common across the country. Some programs focus on developing introductory engineering classes in the elementary school [4], while others have focused on increasing the level of engineering practices in high school STEM and technology classrooms [5]. While the focus of these programs is important in helping teachers to become better facilitators of engineering lessons in their classroom, they do not provide the much-needed support for incorporating engineering practices in science instruction as mandated by the NGSS-based standards.

NGSS mandates science instruction beginning in kindergarten and continuing through high school. This compels elementary teachers, with limited pre-service training in science education and engineering, to develop lessons that meet the standards. Elementary teachers have expressed concerns about their background knowledge and experience in engineering, as well as the limitations on the time needed to develop and teach quality lessons. In one study, 95% of elementary teachers surveyed questioned the relevance of engineering education in elementary grades, primarily due to misconceptions about engineering practices and NGSS implementation [6]. Many of the misconceptions revolved around the notion that students must possess strong reading and math skills to meet with success in engineering lessons. Elementary teachers also articulated a lack of clear understanding of engineering as a discipline [6]. To prepare elementary teachers for successful implementation of NGSS, it is imperative that professional development regarding engineering as a discipline and basic principles of engineering education be offered to elementary teachers at all grade levels.

For middle and high school educators, with an extensive background in science required for content certification, NGSS implementation still presents instructional challenges. The pedagogical shifts, from teacher-centered dissemination of information to a student-centered discovery approach to learning, is one of the challenges and professional development focused on modifying lessons to align to the shifts in NGSS is on-going in many states [7]. Professional development which actively engages teachers in the practices of engineering has been shown to be successful. By engaging in activities that highlight engineering design and its intersection with science content, teachers can effectively integrate engineering practices into their instructional approach. [8]

Workshop Design

A university-based professional development series was offered during the 2023-2024 academic year. Secondary science and elementary teachers were recruited from suburban school districts on Long Island, NY via email sent to district superintendents and science coordinators. To qualify for a participation stipend, all attendees were obligated to attend every session and fulfill a final project. Of twenty-seven teachers that began the program, twenty-five successfully completed all requirements. Participants included elementary, middle, and high school teachers,

teaching all disciplines of science as well as STEM and science research. All workshop sessions were held at Stony Brook University and met for a total of nine hours over four sessions between November 2022 and May 2023. Upon completion of the program, a feedback survey was administered to all participants.

Each workshop session consisted of a discussion about the role of engineering in NGSS, practical ideas for implementation of engineering practices into science lessons, an opportunity for group collaboration and a hands-on engineering activity instructed by university faculty and instructional staff. The major focus of the program was to inform teachers about the pedagogical shifts and to provide practical methods of incorporating engineering practices in the science classroom.

Session one focused on an introduction to the science and engineering practices in NGSS and the engineering design process. After a brief discussion of the development of NGSS and the incorporation of the eight science and engineering practices, participants were given identical sets of seven different components and told to use them to build a specific structure in one minute. There was some initial confusion regarding how to best accomplish the task, but all were able to complete it. After the minute had elapsed, participants were given time to look at the structure that others had created. It was noted that each of them was unique and different from any other. Then participants were given thirty seconds to modify their structure. The purpose of this activity was to introduce participants to key aspects of the engineering design process; namely, that there is more than one solution to a problem and that design revision is an essential step. This activity was followed by a closer look at the progression of engineering standards (ETS) in NGSS from K-2 grade band through HS. The integration of engineering into specific grade-level Performance Indicators was also studied. The session ended with seven specific suggestions on how to begin to incorporate engineering into science lessons. These include beginning accepting and embracing “failure” as an opportunity to learn and to improve, allowing time for inquiry and collaboration, increasing the use and development of models, and having students construct explanations. Teachers then learned how to use a web-based CAD platform to create an individual 3D printed project, which was printed at the university for each teacher. In this activity, participants were exposed to the engineering design process through discovery, to

create a project that had the desired attributes. Participants were then able to create their project to their desired design specifications.

Session two began with a discussion of comparing the established "scientific method" traditionally taught in many science classrooms to the science and engineering practices (SEPs) in NGSS. Participants were given "post-it" notes and told to write one word that describes what scientists and engineers "do" on a note. After a few minutes, participants then placed their notes under a poster listing each of the eight science and engineering practices. Teachers were able to see that each of their words could fit under one of the practices and it was noted that they were able to successfully identify many activities conducted by scientists and engineers. Participants then broke into groups of three or four and were assigned one of the eight SEPs to closely explore. Explanations of each practice from the standpoints of "science' and "engineering" were provided to each group. The groups were assigned the responsibility of creating a poster that illustrated the core concept of their assigned practice, along with highlighting the similarities and differences between the practice in science and engineering. Each group prepared a brief "elevator speech" to explain their assigned practice to the larger group. Following this discussion, participants embarked on a hands-on activity involving the creation of an electronic device, which would be further developed and completed during the remaining two sessions.

The creation of the electronic device is an activity offered by the outreach program at the university. It is a highly customizable activity that has been conducted with students in elementary, middle, and high school. The activity introduces students to the engineering design process and provides instruction in creating prototypes and simulations, as well as the optimization of design, and participants were able to see how this activity exposes students to engineering and could be customized according to the constraints of each class.

The focus of session three was a close look at the Engineering, Technology and Applications (ETS) Performance Expectations (PEs) in NGSS. These PEs are grade-banded, meaning that the same standard is expected to be met in grades K-2, 3-5, middle school and high school and apply to all teachers in each grade band. There are three to four PEs per grade band and each focus on a specific engineering practice: defining and delimiting engineering problems, developing possible

solutions and optimizing the design solution. Participants were provided with a variety of web resources and were given time with teachers in common subject areas and grade bands to brainstorm potential lessons. Teachers were encouraged not to teach engineering as a unit, but to teach engineering practices throughout their lessons. They were reminded to seize the opportunities to revise “failures” as a means of optimizing solutions and to inspire their students to share successes and collaborate whenever possible.

In session four, participants were addressed by the owner of an engineering firm who shared some insight about the field. Discussion about traits that were needed for success in the field were discussed as well as the opportunities available in the job market. An engineering professor at the university then shared information about the different engineering disciplines and led a discussion about this topic. The opportunities available to teachers and their students, and their alignment to NGSS, through the university outreach were also shared and discussed. After completing the hands-on activity, a feedback survey was completed using Qualtrics to collect answers.

Participant Feedback

The feedback survey was completed by 22 participants and was predominantly positive. Participants answered a series of questions using a Likert scale, with 1 as the minimum and 5 as the maximum. The survey questions and results are tabulated below:

Please rate how well this professional development series met your expectations.

Answer	%	Count
1	0.00%	0
2	0.00%	0
3	4.55%	1
4	27.27%	6
5	68.18%	15
Total	100%	22

Please rate how well this professional development series helped you to better your understanding of engineering.

Answer	%	Count
1	0.00%	0
2	0.00%	0
3	0.00%	0
4	27.27%	6
5	72.73%	16
Total	100%	22

Please rate how much this professional development series has increased your understanding and familiarity with the pedagogical shifts in NGSS.

Answer	%	Count
1	0.00%	0
2	0.00%	0
3	0.00%	0
4	45.45%	10
5	54.55%	12
Total	100%	22

Please rate how much this professional development series has influenced your teaching practices.

Answer	%	Count
1	0.00%	0
2	0.00%	0
3	13.64%	3
4	45.45%	10
5	40.91%	9
Total	100%	22

On a scale from 1-5 (1 being not very likely and 5 being very likely), how likely are you to integrate engineering practice into your math and science instruction.

Answer	%	Count
1	0.00%	0
2	0.00%	0
3	0.00%	0
4	40.91%	9
5	59.01%	13
Total	100%	22

Respondents that answered 3 through 5 were asked a follow-up question: *If you answered the last question from 3 to 5, please offer some ideas about how you plan on integrating engineering practice into your science instruction.*

Answers included:

- *The more I can apply what I am teaching in the classroom to real life problems in the community, the greater the understanding my students will have of the topic. The greater the understanding the more effective community members and leaders in the community they become.*
- *I do a lot of STEAM lessons with both my enrichment groups and whole classes in the school makerspace. This course gave me more ideas on ways to incorporate different types of engineering!*
- *The idea of letting students grapple with challenges (and leaving them hanging) was powerful. I have generally picked projects in which they can be successful. I am rethinking this now.*
- *Incorporating groups in my class to develop cost-benefit analysis to mediate complex problems like the climate crisis.*
- *Have my students design and collaborate to build a solution and solve a problem.*

An additional question asked each participant to rate the value of each activity done in the workshop sessions using a Likert scale in which 1 was “not at all useful”, 2 was “somewhat useful”, 3 was “moderately useful”, 4 was “very useful” and 5 was “extremely useful”. The results are tabulated below:

#	Question	Not at all useful	Slightly useful	Moderately useful	Very useful	Extremely useful	Total
1	Overview of NYSSLS	0%	0%	9.09%	36.36%	54.55%	22
2	Discussion of engineering design cycle	0%	0%	9.09%	40.91%	50.00%	22
3	Overview of SEPs (Science and Engineering Practices)	0%	0%	13.64%	31.82%	54.55%	22
4	Engineering progressions in NYSSLS	0%	0%	9.09%	31.82%	59.09%	22
5	Suggestions for how to incorporate engineering in your classroom	0%	4.55%	13.64%	27.27%	54.55%	22
6	Discussion of engineering disciplines	0%	4.55%	9.09%	36.36%	50.00%	22
7	Hands-on project 1	0%	18.18%	27.27%	18.18%	36.36%	22
8	Hands-on project 2	0%	9.09%	13.64%	36.36%	40.91%	22
9	YOUR final project	0%	9.09%	4.55%	27.27%	59.09%	22

Of particular interest are the responses to the final question. Participants were given several options to complete their requisite final project. One option was to offer their students one of the learned activities as a field trip to campus or have us bring our

activities to their school as an in-school field trip; eight participants selected this option. The second option was to re-write one of our activities to be more appropriate for their classroom; four participants selected this option. The remaining thirteen teachers chose the last option, which was to write and instruct an engineering lesson for their class and allow us to observe the lesson. Lessons ranging from elementary coding of robots to AP biology signal processing and honors physics determining the resistance of Play-Doh. All lesson plans were required to be aligned to at least one Performance Expectation in NGSS. The integration of engineering principles into instruction was encouraging to see, as was the role of teachers in supporting students as they navigated challenges.

As a final feedback question, participants were asked to provide any additional comments. Again, the comments were very positive, mostly expressing gratitude for the opportunity to participate in the program. Some specific comments were:

- *Thank you so much! All of the deep dives into the NGSS requirements and engineering expectations were very helpful! I learned a lot and have lots to bring back to our district to discuss.*
- *I would highly recommend this program to other teachers and the use of the [university] lab to be used by other students.*
- *This was a very useful and practical PD. I am excited to bring my class here next week to do the same project. I hope it helps inspire some future engineers!!*
- *I had a lot of background knowledge for the Science standards, shifts, and NGSS coming into the course. I enjoyed the experience of extending advanced concepts like electrical engineering to elementary students.*

Future plans

As this professional development program was so successful, a second cohort of teachers is meeting during the 2023-2024 school year. Some modifications and adjustments, based on suggestions made in the feedback survey were made. Twenty-six teachers are meeting and anecdotal feedback has been very positive.

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