NGSS TEACHER PROFESSIONAL DEVELOPMENT TO IMPLEMENT ENGINEERING PRACTICES IN SCIENCE INSTRUCTION

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SUBJECT/PROBLEM

There are significant challenges as states transition their science standards to align with the *Next Generation Science Standards* (NGSS Lead States, 2013). The primary goal of the standards, based on the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, is to empower all students with the requisite scientific and technological literacy to make informed personal and public decisions and the motivation and skills to pursue potential careers in STEM fields (NRC, 2012). Historically, attempts at educational reform have often been unsuccessful in terms of the rate and scope of change. A number of factors contributed to these issues, such as lack of involvement of educators in policy-making, insufficient professional development and support for teachers, stakeholder resistance to change, inconsistency of implementation, and inadequate time and curricular resources (Anderson & Helms, 2001). A significant obstacle to the success of NGSS implementation is the inadequate preparation of science teachers to address the engineering components of the standards. Without additional support it is likely the engineering practices will be avoided or misrepresented in the classroom, undermining the objectives of NGSS (Purzer et al., 2014). These potential pitfalls must be addressed to encourage widespread adoption and implementation of the NGSS in science classrooms throughout the U.S.

The integrative nature of NGSS presents a unique challenge for classroom teachers and teacher educators. One of the primary aims of NGSS is the incorporation of engineering practices with science content in a cohesive course (NGSS Lead States, 2013). Very few science educators have either educational or practical experience with engineering and many have significant misconceptions or a complete lack of knowledge of engineering (Bybee, 2011; Kimmel et al., 2007). As a result, there is a need for professional development for science educators that will foster participants' engineering literacy. Accessible and effective teacher training that contributes to the development of teachers' awareness of engineering and the associated pedagogical practices can increase the likelihood that students will experience NGSS-aligned instruction as intended (Darling-Hammond et al., 2017; Yoon et al., 2007).

In response to this critical need, this research examined the influence of an engineering professional development experience on science teachers' perceptions of engineering in the science classroom as well as their own perceived ability to teach engineering. Current literature is generally deficient in reporting on the attitudes and approaches of science teachers with regards to the inclusion of engineering in their courses. Following their involvement in a multi-session professional development workshop in engineering practices for science educators, this study investigated two questions about the impact of this experience on teachers and their beliefs regarding the integration of engineering in their science courses:

1. How does professional development in engineering education affect secondary school science teachers' beliefs about the value of using engineering design to support science learning?
2. How does professional development in engineering education affect secondary school science teachers' self-efficacy regarding teaching engineering in their science courses?

Theoretical framework. The preparation of science teachers to incorporate effectively the principles of engineering to supplement science content and curricula requires the development of teachers' content knowledge and pedagogical content knowledge in the engineering design process (ASEE, 2014). In addition to the challenges associated with engineering instruction, there are deficiencies in the current practices of teaching science that will likely impede the successful implementation of NGSS. Science instruction often emphasizes the coverage of content without providing students with opportunities for developing deeper understanding or drawing connections between learning in different contexts (Linn et al., 2006). The knowledge integration perspective of cognition has been evidenced in student learning. Since research has indicated that effective professional development models intended teaching practices, it is logical to use the knowledge integration framework to guide both classroom and professional development experiences (Knapp, 2003; Lee et al., 2010).

DESIGN/PROCEDURE

Research design. The quasi-experimental, observational design involved a self-selected treatment group of middle and high school science and mathematics teachers, as well as a randomly selected control group of similar teachers who did not participate in the treatment. Most of the self-selected participants were also involved in a state-sponsored Master Teacher Program, requiring teachers to participate in 50 hours of professional development per year. Data were collected from 37 participants in the two workshops. A total of 23 teachers responded to both the pre- and post-workshop surveys during the electrical engineering workshop and 14 teacher participants replied to both surveys during the bioengineering sessions. Six of those participants attended both the electrical engineering and bioengineering workshop series. Additionally, a control sample of 28 teachers completed the same survey; these teachers were not from the Master Teacher Program. All respondents were either middle or high school STEM teachers who were actively teaching in a variety of suburban school districts located throughout Long Island, New York.

Workshop structure. The workshops were developed collaboratively between university science education and science and engineering faculty based on recent literature regarding high quality teacher professional development. As such, the workshops focused specifically on the engineering design principles emphasized throughout the NGSS and American Society for Engineering Education (ASEE) standards (ASEE, 2014; NGSS Lead States, 2013). Class sessions were co-instructed by science education and science and engineering faculty. To maximize broader impacts, workshops were presented in two modules: 1) electrical engineering co-instructed with physics education faculty (6 hours); and 2) biomedical engineering co-instructed with biology education faculty (4 hours). Each module addressed disciplinary core ideas, crosscutting concepts, and science and engineering practices through theory-based readings and discussions, hands-on tasks, and collaborative curriculum design. Consistent with NGSS, the workshop activities were framed for identifying problems and defining related limitations and criteria for technological advancements. Teachers generated and evaluated a variety of solutions to identify problems. They built several devices, including a home security system, a night light, and a biofuel cell, and optimized solutions through analysis of the value and costs associated with their designs (NGSS Lead States, 2013). They modified the functionality of their devices and tested them before taking them back to their classrooms. Teachers also attended sessions that focused on preparing and advising students on engineering-related post-secondary study and careers.

Data collection. The *Master Teacher Engineering Professional Development Survey* (Table 1) was used to measure various aspects of participants' familiarity with engineering and self-efficacy in teaching engineering prior to participation in each workshop series and again at the conclusion of each series. The survey was modified from two existing validated, reliable questionnaires – the *Teaching Engineering Self-Efficacy Scale* (Yoon et al., 2014) and the *Familiarity with Design, Engineering & Technology (DET) Survey* (Yasar et al., 2006). The survey was administered once to a control group of demographically similar science teachers from the same geographic area. The survey administered to participants prior to the workshops as well as the control group survey were also used to collect background information about teacher education, certification, teaching experience, and prior professional development and teaching experiences in engineering. The 20-question Likert inventory used in both the pre- and post-professional development surveys had a high internal consistency (Cronbach's $\alpha = 0.97$). Teachers responded on a six-point Likert-scale (1=strongly disagree to 6=strongly agree), self-assessing their ability to accomplish the tasks described in Table 1.

Table 1. *Master Teacher Engineering Professional Development Survey*

In my role as a teacher, I am able to… (*n*=37)	**Pre-Survey Mean (*SD*)**	**Post-Survey Mean (*SD*)**	**Paired Samples *t*-score**	**Effect Size (*d*)**
1. Explain engineering concepts well enough to be effective in teaching engineering.	3.70 (1.46)	4.52 (1.16)	2.475*	0.62
2. Assess students' engineering products.	3.65 (1.47)	4.38 (1.13)	2.837**	0.56
3. Employ engineering activities in my classroom effectively.	3.67 (1.47)	4.38 (1.13)	3.463**	0.82
4. Explain the ways engineering is used in the world.	4.12 (1.34)	4.70 (0.99)	4.256***	1.05
5. Describe the process of engineering design.	3.81 (1.44)	4.59 (1.05)	2.690*	0.62
6. Create engineering activities at the appropriate level for my students.	3.62 (1.36)	4.46 (1.21)	2.668*	0.65
7. Select appropriate materials for engineering activities.	3.48 (1.37)	4.41 (1.19)	3.283**	0.73
8. Recognize and appreciate the engineering concepts in my subject area.	4.00 (1.44)	5.00 (0.85)	3.606**	0.85
9. Guide my students' solution development in learning the engineering design process.	3.67 (1.44)	4.70 (1.03)	4.098***	0.82
10. Increase students' interest in learning engineering.	4.15 (1.49)	5.23 (0.65)	3.742**	0.94
11. Help students apply their engineering knowledge to real world situations.	3.85 (1.41)	5.12 (1.03)	4.282***	1.03
12. Promote a positive attitude towards engineering learning in my students.	4.52 (1.50)	5.52 (0.58)	3.312**	0.88
13. Encourage my students to think creatively during engineering activities and lessons.	4.37 (1.47)	5.37 (0.79)	2.962**	0.85
14. Encourage my students to think critically when practicing engineering.	4.15 (1.41)	5.19 (0.92)	3.054**	0.87
15. Encourage my students to interact with each other when participating in engineering activities.	4.31 (1.46)	5.38 (0.70)	3.674**	0.93
16. Inform my students about engineering careers.	4.07 (1.71)	5.37 (0.63)	4.306***	1.01
17. Differentiate between engineering disciplines.	3.63 (1.60)	4.96 (0.98)	4.163***	1.00
18. Recommend relevant high school courses to students interested in pursuing engineering.	4.07 (1.66)	5.26 (1.06)	3.986***	0.85
19. Modify my curriculum to comply with the Next Generation Science Standards (NGSS) and/or the New York State Science Learning Standards (NYSSLS).	4.07 (1.54)	4.70 (1.03)	2.148*	0.48
20. Acquire the resources for implementing NGSS and/or NYSSLS.	3.96 (1.48)	4.74 (0.98)	2.487*	0.62
Overall Composite	**78.40 (25.19)**	**99.96 (12.83)**	**4.479*****	**1.07**

$^{*}p<.05$; $^{**}p<.01$; $^{***}p<.001$

Quantitative data were analyzed through surveys administered electronically. Pre- and post-experience within-group and between-group differences were analyzed with inferential statistics. Independent-samples and paired-samples t-tests provided measures of change attributable to the professional development experience while controlling for other variables associated with the program participants. In this case, the comparison of means identified any significant differences between the responses of the control group and the post-experience survey responses of teacher participants, while also comparing pre- and post-experience responses of the participants**.** Missing data were deleted listwise since there were so few incomplete responses.

RESULTS/ANALYSIS

To improve external validity, the pre-survey composite scores of the treatment group were compared to a control group. Independent-samples t-tests indicated no differences between the two mutually exclusive groups (t=0.840, df=62, p=.404) on the pre-survey (M_{control}=83.86, SD= 16.59; $M_{\text{treatment}}$=79.67, SD= 21.95). This showed that the teachers in the treatment group were similar to the general population of teachers in New York State in terms of engineering knowledge and skills, pedagogical content knowledge, and ability to differentiate engineering disciplines.

To measure the effectiveness of the engineering professional development, a paired-samples t-test was conducted with the treatment group to compare mean composite survey scores before and after the workshop. The teachers significantly improved their self-assessed engineering knowledge and skills (t=4.479, df=24, p<.001, 95%CI[11.6, 31.5]) from pre-survey (M=78.40, SD=25.19) to post-survey (M=99.96, SD=12.83), with a large effect size (d=1.07). The teachers improved their self-assessed ability to teach engineering, modify their curricula to comply with NGSS, and advise students on preparing for engineering study and careers; their mean scores on every survey item increased significantly from pre- to post-workshop, as indicated in Table 1.

Although teachers significantly improved in many areas of engineering knowledge and instruction, the effect sizes ranged from medium (d=0.48) to large (d=1.05). The teachers reported very large improvements in their ability to: 1) use engineering activities in the classroom effectively, 2) increase students' interest in engineering, 3) help students apply engineering to real-world situations, and 4) advise students on different engineering disciplines and careers, as well as how to prepare for them before college. The lowest effect size was reported in their ability to modify their curricula to comply with NGSS (d=0.48). Although the teachers had significant gains in their self-assessed ability to do so, the researchers felt an additional workshop session might be warranted to focus specifically on curriculum writing and alignment. Most teachers administered state standardized culminating exams in their content areas, which had not yet been re-aligned to NGSS. This constraint may have impacted their confidence in making curricula changes before the exam items reflected NGSS.

IMPLICATIONS FOR TEACHING/LEARNING OF SCIENCE

The results from this study demonstrate that a university-based professional development workshop series is an effective intervention to improve the engineering knowledge and skills of secondary STEM educators, ultimately increasing NGSS adoption in classroom instruction. These engineering education workshops were designed by university faculty in science education, physics, and engineering within a knowledge integration framework, whereby professional development experiences promote the acquisition of new knowledge through opportunities to employ the engineering practices in the context of scientific phenomenon (Chiu & Linn, 2011).

Applying science principles in devising solutions to technological problems is foundational to NGSS (NGSS Lead States, 2013). Innovative, scalable professional development experiences are necessary to model how engineering practices might be incorporated in secondary science and mathematics curricula. University faculty are best positioned to share the knowledge and skills of professional engineers in an appropriate pedagogical framework for K-12 standards adoption. An additional implication from this study is the importance of educating precollege teachers on engineering disciplines and careers. Due to their frequent interactions with students, they are well positioned to provide advisement on engineering careers both formally and informally.

CONTRIBUTION TO INTEREST OF NARST MEMBERS

It has been the case with large-scale education reform efforts in the past that limited continuity of implementation was a barrier to reform success. Programs specifically targeting teacher leaders from different districts can be a relatively inexpensive investment that can initiate progressive change through the actions of motivated and respected colleagues. Continued education and demonstration of the unity between science and engineering, as was demonstrated in the activities conducted during these workshops, are necessary to facilitate fidelity of NGSS adoption. Ultimately, teachers need support from a network of colleagues, innovative administrators, university partners, and state policy-makers and standards writers in order to carry out reform in the classroom.

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