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High School Chemistry Teachers' Views of Engineering Inclusion Before and After a Professional Development Program

by Sarah B. Boesdorfer

The *Next Generation Science Standards* (NGSS Lead States, 2013) represent several conceptual shifts for K-12 science education, including the inclusion of aspects of engineering in the science classroom. This new need to teach engineering concepts worries many science teachers (Boesdorfer & Staude, 2016; Haag & Megowan, 2015), likely because they have had little or no experience with engineering (Banilower et al., 2012). Teachers' knowledge and beliefs about a subject and its teaching affect what they do in their classrooms (Keys & Bryan, 2001; Van Driel, Berry, & Meirink, 2014). Thus, teachers' understanding of engineering and how it can be incorporated in the science classroom will affect the translation of NGSS to science classrooms.

The purpose of this study was to understand high school chemistry teachers' knowledge of engineering and incorporation of engineering in their chemistry classes before and after a professional development (PD) program. Its findings can inform efforts to help teachers effectively incorporate NGSS into their science classrooms.

Engineering in NGSS

NGSS advocates for K-12 students to learn both 1) engineering *skills or practices*, described in NGSS as Science and Engineering Practices (SEPs), and 2) engineering *content*, described in NGSS as the Engineering, Technology, and Applications of Science (ETS) Performance Expectations or Disciplinary

Considerations for Science Education PD Providers

(see pp. 4-6 for more details)

- ◆ Teachers view engineering positively, but likely have naïve view of it, assuming it is more similar to science than it is.
- ◆ As with most preconceptions, teachers' preconceptions about engineering are difficult to change.
- ◆ Science teacher educators should focus on helping science teachers learn to incorporate the processes/skills of "defining problems" and "optimization" into their classroom.
- ◆ When curriculum reform requires changing teacher preconceptions, intensive and sustained professional development is necessary.

Core Ideas (DCIs). Cunningham and Carlsen (2014) argue the ETS core ideas are “statements of practices” (p. 198), thus teachers should focus on including engineering *practices* and *process* in their science classroom, rather than looking to NGSS for *engineering content knowledge*, DCIs, to teach. In addition, Appendix K in NGSS (NGSS Lead States, 2013) presents engineering design as a *process* with three distinct components: 1) Defining problems, 2) Developing solutions, and 3) Optimizing solutions, which supports Cunningham and Carlsen’s argument. The study and PD program described here both used this definition: **engineering in the science classroom means engaging students in the *engineering design process* through which students learn and develop engineering practices and ways of thinking.**

RESEARCH QUESTIONS

This study was guided by two research questions:

1. How do high school chemistry teachers view *engineering* before and after a professional development program on engineering inclusion in the science classroom?
2. How do high school chemistry teachers view *the incorporation of engineering in the science classroom* before and after a professional development program on engineering inclusion in the science classroom?

METHODS

Context

This study focuses on outcomes for high school chemistry teachers after participating in a PD opportunity entitled *Engineering Activities for Teaching Chemistry [EATC]*, sponsored by the Center for Educational Transformation at the University of Northern Iowa. The goal of EATC was for teachers to learn about and design activities for high school chemistry that both address the engineering practices/standards from NGSS and teach or assess chemistry content.

EATC started with a one-day workshop focused on the engineering practices and design process described in NGSS, including the engineering design loop (see Figure 1) and the 5E learning cycle (Bybee et al., 2006). Following the workshop, teachers participated in monthly two-hour meetings online, during which they

learned about an aspect of engineering incorporation in their classes (e.g., assessment, common misconceptions) for part of the meeting time, and then worked in small groups to develop engineering activities for their classes and received feedback from other groups on their activities. Each group of teachers developed three activities. Between sessions, teachers continued to develop their activities and were encouraged to test them in their classrooms, though not all were able to do so by the end of the program.

More information about EATC and *drafts* of the activities developed by the teachers can be found at <http://tinyurl.com/ohqzwdc>

Participants

Of the 24 teachers who participated in the PD program, 23 ($N = 23$) completed all of the data collection instruments: 6 males and 17 females. All the teachers taught high school chemistry in Iowa and a large majority (18) taught at least one course other than chemistry--e.g., physics or physical science. On average, they had been teaching for 11.4 years.

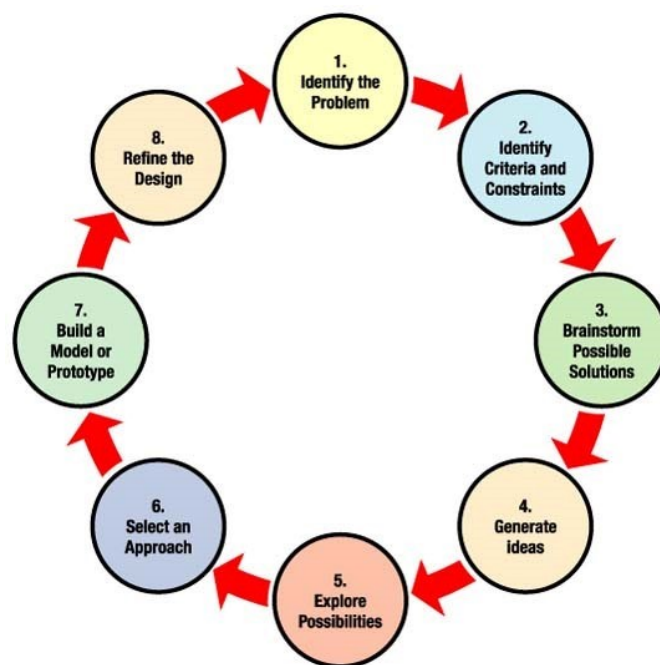


Figure 1. Engineering Design Loop
(Daugherty & Custer, 2003 from Boesdorfer & Greenhalgh, 2014)

Data Collection

Prior to the initial workshop, all participating teachers completed an online survey which asked about demographics, their classroom practices, and engineering generally and engineering in the science classroom. The questions about teachers' classroom practices and the impact of the PD on their teaching have been reported elsewhere (Boesdorfer, 2017).

Survey questions were modeled on other instruments (Marshall, McClymont, & Joyce, 2007; Meyer, Owens, Cargile, & Koenig, 2014; Museum of Science, Boston, 2014) including a set of questions which provided teachers with a short description of students' actions in a classroom (e.g., "After learning about plate tectonics, an 8th grade science teacher has students create toothpick and marshmallow structures. They then test their strength on a shake table.") and asked them to explain if the students were engaging in engineering or not. At the end of EATC the teachers completed another online survey which included the same engineering questions along with questions about their experience in EATC.

In addition to the surveys, the activities developed by the teachers in their groups were collected.

Data Analysis

The multiple choice and Likert-scale questions from the surveys were statistically analyzed using SPSS. Along with descriptive statistics, correlational analysis of questions and *t*-tests for the pre and post survey questions were performed using a significance level of 0.05 or less. Answers to open-ended questions were coded using a constant comparative coding method (Maykut & Morehouse, 1994). The open-ended survey questions were coded. Table 1 provides the final coding categories used based on aspects of the engineering design. Other than the "not codeable" category, the developed categories represent characteristics of engineering design advocated as important for inclusion in K-12 education (Daugherty, 2012).

The lesson plans were assessed using a rubric designed to capture the aspects of the engineering design process as defined in NGSS (NGSS Lead States, 2013) utilized by the students during the activity, along with the important

Table 1. Final Coding Categories for Open-ended Questions Relating to Engineering

Code	Description	Example Response in the Category
Not Codeable	Unclear, simply repeated the prompt, or was off topic.	"It could lead to engineering work but as it stands it is not yet there"
Real-life	Engineering relates to community, the world, or "real-life."	"Create a story and data to match the actual graphing scenario"
Problem	Engineering requires a problem to be solved.	"Modify their design to make the rocket do something in particular--like go a minimum of 20 feet and a maximum of 30 feet high"
Apply Knowledge	Engineering requires people to apply/use scientific knowledge.	"designing or application of a concept"
Design and Test	Engineering requires making/design of a product which is tested to see if it meets criteria.	"Students are creating their own structures and then testing their design"
Revise and Retest	Engineering is an iterative process in which designs are tested and <i>redesigned</i> (improved) before being finalized.	"There is a test phase and either an opportunity to improve a new structure or a
Prototype	Engineering develops small or sample versions of products to test prior to the final or scaled-up version(s).	"Design and analysis of model to apply to larger problem"

aspects of engineering in the classroom--e.g., the problem being solved has numerous possible solutions. Not all lesson plans provided by the EATC participants were assessed with the rubric, due mostly to incompleteness or vagueness of the lesson plan. Nineteen of the 25 lesson plans were scored with the rubric.

FINDINGS AND DISCUSSION

Research Question 1: Views of Engineering

Survey findings. The multiple-choice and Likert-scale questions from the teacher surveys revealed that, prior to EATC, the teachers in this study held a more positive and accurate, though maybe incomplete, view of engineering than the general public (e.g., Marshall, McClymont, & Joyce, 2007). They thought engineering was *creative* (mean = 4.78 on a 5-point scale), involved *thinking* (mean = 4.83) and was *exciting* (mean = 3.91); they did not associate it strongly with negative words like *routine* (mean = 2.45) and thought it was important to understand (mean = 4.17).

However, the responses to two of the questions indicate possible naïve or incorrect conceptions of engineering. First, many of the teachers agreed with the statement “Engineers fix things” (mean = 3.78), a naïve conception of engineering (Marshall et al., 2007; Museum of Science, Boston, 2014). Moreover, agreeing with the use of the word *things* might indicate the teachers believe engineering must create a product, a thing, rather than the option they could develop a process. Other research has documented this misunderstanding among teachers (Antink-Meyer & Meyer, 2016).

The other concerning response was that the teachers agreed strongly with the statement “Engineers are very similar to scientists” (mean = 4.13). While *The Framework for K-12 Science Education* (NRC, 2012) presents science and engineering practices together, emphasizing the similarities between them, it does not distinguish the differing emphases of scientists and engineers in their use of these similar practices (Cunningham & Carlsen, 2014). Thus, the teachers may not fully recognize the differences between science and engineering in practice.

⇒ **Teachers view engineering positively, but likely have naïve view of it, assuming it is more similar to science than it is.**

There was no statistically significant difference in the teachers’ responses from the first survey to the second survey. Though some of the averages were numerically different, it cannot be stated that this reflects an actual change in the teachers’ views. Reasons for the lack of change in the teachers’ response include high, accurate responses on the initial survey, a small sample size ($N = 23$), and the brief period between the administration of the surveys (November to May).

⇒ **As with most preconceptions, teachers’ preconceptions about engineering are difficult to change.**

Research Question 2: Views of Engineering Inclusion

Survey findings. Prior to PD, science teachers had a simple definition of engineering incorporation in the science classroom and did not recognize the need to acknowledge the iterative nature of the engineering design process. The pre-EATC survey asked the teachers how they are including or might include engineering in their classroom. Thirty percent (7 of 23) of the chemistry teachers could not clearly answer the question. Table 2 presents the results of the coding of the remaining teachers’ answers (Note: A teacher’s response could be coded into more than one category). Even those who provided an answer did not provide many details, and only one teacher described engineering design as an iterative process encompassing revisions and redesign. The teachers provided better descriptions of engineering in the science classroom when provided with specific teaching scenarios (see row 2 in Table 2). With the scenarios, some teachers (34.8%) mentioned the idea of creating a prototype during the engineering design process, which was not mentioned at all in the open-ended prompt. As Table 2 indicates, for most of the teachers, prior to EATC, engineering in the science classroom involved students designing something which they would test as a solution to a problem presented to them. The activity also should be contextualized in a “real” situation which could be contrived for the classroom. While the teachers had some understanding of engineering in the classroom, as with their understanding of engineering in general, the definition was simple--real world with a problem to design for--and missed important aspects of engineering design.

Findings from the lesson plans. First, post-PD, teachers understood engineering in the classroom to involve activities with a problem to solve in real-world context,

Table 2. Number of Teachers with Responses Coded in Each Category (N = 23)

	Real-life	Problem	Apply knowledge	Design and test	Revise and retest (modify)	Prototype
How to include engineering in your class?	7 (30.4%)	6 (26.1%)	4 (17.4%)	6 (26.1%)	1 (4.3%)	0
Engineering in the teaching scenarios	13 (56.5%)	13 (56.5%)	7 (30.4%)	15 (65.2%)	9 (39.1%)	8 (34.8%)

but struggled to understand how to allow students to move beyond a novice level of defining the problem themselves. The teacher-developed lesson plans allowed for assessment of the teachers' understanding of the inclusion of engineering in their classrooms after the PD. All 19 lesson plans assessed had a realistic problem for students to address, an important aspect of engineering design (Daugherty, 2012). Each teacher seems to have grasped this aspect of engineering. In terms of the "defining the problem" stage of engineering design, 18 of the lesson plans provided students with the problem along with the constraints and criteria, rather than asking them to clarify the problem or even define the criteria and constraints themselves. Beginning designers often approach problems by assuming "givens" in the definition of the problem (Crismond & Adams, 2012).

Next, post-PD, teachers understood developing solutions using scientific knowledge and/or experimentation as part of the engineering design process in the classroom the best. In their activities, students were asked to "research and explore multiple solutions," an important part of the "developing solutions" stage of engineering design (Appendix I, NGSS Lead States, 2013). Ten of the 19 activities asked students to experiment with variables to understand the situation and possible solutions, and the other activities asked students to explicitly draw on their scientific knowledge of the variables learned in previous lessons. While engineers use experimenting for evaluation and scientists for hypothesis testing (Cunningham & Carlsen, 2014), there is strong overlap in this stage of the engineering design process and the practice of science, so it is not surprising that science teachers included this familiar process in their activities.

Finally, post-PD, teachers continued to struggle to understand the need for the iterative nature of the design process to be part of engineering incorporation in the classroom. After EATC, the optimization stage of engineering design was still not reflected strongly in the

lesson plans. Only 4 of the 19 activities required students to redesign their solution and test it again or provide a redesign in their reporting of the findings without a test. Three activities asked students to indicate what they would do differently if they did the activity again, although the prompt was not explicit about improving their design. As with the "defining the problem" stage of engineering design, activities without an aspect of redesign miss the opportunity to teach students about the iterative nature of engineering design (Cunningham & Carlsen, 2014).

LIMITATIONS

Though it had characteristics of an effective PD program--e.g., community development between the teacher participants--EATC was relatively short with few program meetings, whereas sustained PD programs have been shown to be much more effective for teacher development (Loucks-Horsley et al., 2010). In addition, this study did not explore the teachers' use of the activities in the classroom. Since enacted curriculum is often different than written (Porter & Smithson, 2001), some of the missing aspects described above might appear in the actual implementation of the activity. As evident in their lesson plans, EATC made some gains in the teachers' understandings of engineering in their classrooms and provided them with an initial step toward engineering inclusion and meeting the goals of NGSS.

IMPLICATIONS

Science teachers quickly and easily grasp the aspect of including the "developing solutions" part of the engineering design process when incorporating engineering in their classrooms, but continue to struggle with the other aspects, "defining the problem" and "optimization."

⇒ **Science teacher educators should focus on helping science teachers learn to incorporate the processes/**

skills of “defining problems” and “optimization” into their classroom.

Science teachers likely hold a positive and reasonable view of engineering, but it is probably also a naïve view with some common misconceptions. However, changing these preconceptions, as with changing most preconceptions, is difficult. Though many preconceptions were explicitly addressed during EATC, insufficient time for teachers to change their thinking may have been given.

⇒ **When curriculum reform requires changing teacher preconceptions, intensive and sustained professional development is necessary.**

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