AN INVESTIGATION OF THE PREPARATION OF SCIENCE TEACHERS

TO INCORPORATE ENGINEERING DESIGN PRINCIPLES

INTO THEIR SCIENCE CURRICULA

by

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ABSTRACT

Incorporating engineering design principles into science curricula is part of the Next Generation Science Standards (NGSS) with an intended purpose of moving science education forward to the 21st century. This study examined teacher preparation, attitudes, and level of knowledge about the engineering design process and how it can be incorporated into their science curricula. Teachers were surveyed for their perceptions of and experiences with engineering concepts. In general, science teachers need more professional development in order to meet the goal of properly incorporating engineering design into their science class(es) regardless of whether they live in a state that has adopted NGSS or not. Professional development that makes a difference is focused and on-going embedding engineering experiences with content very much in the same way that teachers are expected to teach their students. Professional, on-going and expert support proved to be a key element to the science teacher's development as an effective educator.

INTRODUCTION AND BACKGROUND

This project originated out of a need to understand the changing science standards for K-12 schools. I work at Indiana Connections Academy, a virtual K-12 school that is completely online and mostly asynchronous. Students work on a semester basis and have a curriculum to complete during that period of time; a planner on their dashboard lays out which lessons should be completed on a daily basis and also reminds them if they are getting behind. As a teacher my role is to monitor student progress and achievement, to hold weekly synchronous lessons which typically last one hour per course, and to call students throughout the semester to check on them while providing a personal touch. My teaching load is typically 2 different science courses with around 300 students. My homeroom consists of approximately 40-45 students per semester and it is with these students that I have the most voice contact with as I am their primary support system to navigate school. My fellow teachers and I have monthly science department meetings and weekly professional learning community (PLC) meetings to discuss what our students are struggling with in the content, to review our own class data and discuss and share materials for upcoming lessons. We also modify some of the portfolios, a generic term used across the curriculum for original student work and in the case of science it is usually a lab report, so that they are more student-friendly, rigorous, and engaging for our students.

My primary teaching responsibility is to teach Integrated Chemistry and Physics to 9-12 grade students. Most of the students I teach are enrolled in this course. Semester one has a chemistry emphasis and semester two has a physics emphasis. Many students

struggle with completing portfolios and have a difficult time remembering and connecting what they learned from first semester to what they are learning in the second semester. There is little connection to engineering design in the existing curriculum. Indiana has not adopted NGSS although it has placed the 8 Science and Engineering Practices contained within NGSS into the revised science standards released on April 15, 2016, and called them science and engineering process standards.

> The Science and Engineering Process Standards are the processes and skills that students are expected to learn and be able to do within the context of the science content. The separation of the Science and Engineering Process Standards from the Content Standards is intentional; the separation of the standards explicitly shows that what students are doing while learning science is extremely important. The Process Standards reflect the way in which students are learning and doing science and are designed to work in tandem with the science content, resulting in robust instructional practice. (Indiana Department of Education, 2016, Science Standards webpage)

Teachers at my school have not received any professional development with regard to these updated standards and the curriculum has not changed to reflect the implementation of these new standards. As a result, I wondered what I should be doing, what my colleagues should be doing, what my school should be doing, and what the state of Indiana should be doing to train and develop all of its teachers to incorporate these newly introduced standards. This is what led to my interest in this project; it was perfect timing for my capstone project.

Science education content and teaching methods are ever evolving. Many changes have taken place over the last 15 years or so including the development of the Next Generation Science Standards (NGSS). NGSS are the current gold standard of

science standards nationally. How they came about is best captured in this quote from

the frequently asked questions (FAQs) section on the website www.nextgenscience.org,

> NGSS was a state-led effort (of 26 different states). In addition to states, the National Research Council (NRC), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and other critical partners were active in the development and review of the NGSS and will continue to provide significant support to states as they consider adoption and implementation of the standards. Writing and review teams consisted of K–12 teachers, state science and policy staff, higher education faculty, scientists, engineers, cognitive scientists, and business leaders. Achieve managed the development process on behalf of the lead states. The NGSS writing process began in the summer of 2011, and the final version of the NGSS was released in April 2013 (NGSS, 2016, FAQ #3).

Integration of engineering concepts into science curricula is one of three main

tenants of NGSS. The other two are disciplinary core ideas which many states already

have on the books and crosscutting concepts which recognize and articulate the

underlying scientific concepts such as pattern recognition, cause and effect, synthesis and

decomposition, etc. In this study, teachers were surveyed to observe how well prepared

they are to manage integrating engineering design concepts into their science class(es).

Solid teacher preparation along with contemporary, realistic and achievable professional

development are the cornerstones to realizing the goals of NGSS which are: 1) to prepare

all American students to be informed citizens in a democracy and to be knowledgeable

consumers, 2) for the nation to compete and lead in the global economy, and 3) to be able

to pursue expanding employment opportunities in science-related fields. To achieve those

goals, a solid K–12 science education that prepares them for college and careers is a must

(NGSS, 2016, FAQ #1). Presently there are 17 states and the District of Columbia that

have adopted NGSS to guide and align their science curricula which makes this capstone

project relevant today and for the foreseeable future (Figure 1).
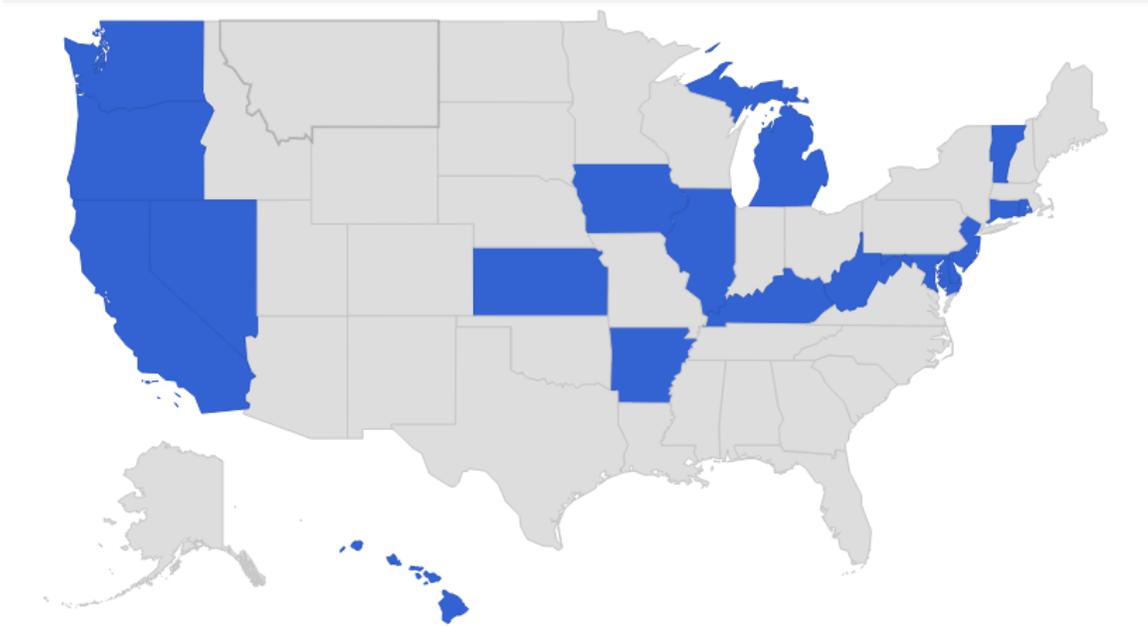
Figure 1. States that have adopted NGSS, as of 6/21/16 (Academic Benchmark, 2016, NGSS Adoption Map and National Science Teachers Association, 2016, NGSS Blog).

This project creates a set of baseline data from teachers all around the country as

well as two internationally located teachers to begin to get a picture of where teachers are

currently in their own understanding of the engineering design process, how well

prepared they are to integrate engineering concepts into their science class(es), how

relevant teachers view this to the science discipline(s) they teach and to determine if

previous professional development and/or college coursework makes a difference when it

comes to understanding it, being able to feel comfortable with it and ultimately

effectively teaching it to the next generation of students.

CONCEPTUAL FRAMEWORK

Science standards have changed significantly in the last 20 years in response to changing demands upon schools by varying levels of government, business models and the community of which teachers, students and parents are apart. The most recent emphasis has been placed on scientific literacy with the integration of scientific inquiry into science curricula and now engineering design practices with the latest set of standards, the Next Generation of Science Standards (NGSS).

National Research Council (NRC) highlighted "scientific inquiry" as the core of science teaching and learning through which students "develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NGSS, 2013, Appendix D). Research is still being conducted on how effectively scientific inquiry is being integrated into all grade levels of science, K-12, because it is considered an integral part of every science course regardless of the grade level. DiBiase and McDonald (2015) found through surveying 275 middle and secondary school teachers in four districts in North Carolina that generally, teachers felt that inquiry was important for the students to learn and participate in, they did not feel that they had the necessary skills to implement and manage inquiry in the classroom properly nor did they feel that there was enough of a benefit to the students to do inquiry exercises when they also had to prepare for end-of-year state assessments (DiBiase and McDonald, 2015). As a result they came to the conclusion that due to the contrasting data, there is a lack of understanding of inquiry and how to implement it in the classroom.

There are a number of statistics available that point to the urgency of getting students prepared for and interested in science jobs in general but specifically engineering. According to Nugent, et al. (2010), the U.S. is producing fewer engineering and technology professionals while other countries are increasing the number of students graduating in these fields. According to the Trends in International Science and Math Study (TIMSS), conducted in 46 countries, 15 countries are higher achieving in math and 8 countries are higher achieving in science as compared to the U.S. (Nugent, et al., 2010). These numbers become even more important when looking at the Bureau of Labor Statistics which forecasted in 2009 (BLS, 2009) that scientific and engineering occupations were "expected to increase by 70% with 1.25 million jobs to be added by 2012" (Nugent, et al., 2010, p. 14). Vessel pointed out that an even more staggering finding that the research Nugent, et al. conducted which corroborated the BLS statistic that "150, 931 engineers were needed in 2008 but 74,170 students graduated from U.S. engineering programs with a Bachelor's degree and those numbers are expected to grow by only 10.1% over the next 10 years until 2018" (Vessel, 2011, p. 7). There is clearly not enough supply of U.S. engineers to meet the demand needed by U.S. companies which is where role of the K-12 teacher becomes vitally important, "it is accepted that the quality of engineering graduates is impacted by the quality of K-12 educators and his/her content area knowledge" (Vessel, 2011, p. 2). The reason for this is that students begin to legitimately envision what they want to be as an adult once they begin formal schooling on the elementary level with the greatest number of students deciding their careers as

high schoolers, especially when it comes to science careers, because that is where the real

challenges in science content begin to take place.

Just as NGSS were being developed, many researchers were coming to the

conclusion that engineering or engineering design was the appropriate avenue to achieve

the goal of technological literacy so desperately needed to bring the performance level of

students to an acceptable minimum standard (Vessel, 2011). NGSS were finalized in

2013. Sticker paraphrased the intent of NGSS very well by stating,

> the basic need for all students, in their pursuit of preparing for life, work,
> and citizenship in a society inundated with technology, is to possess a
> fundamental understanding of the nature of engineering…allowing time for
> students to wrestle with the iterative nature of open-ended problems, deeper,
> more meaningful and transparent understandings can occur (Stricker, 2011,
> pp. 65 & 94).

One of the biggest and significant differences is the integration of engineering and

technology into the structure of science education that was not there previously. "This

integration is achieved by raising engineering design to the same level as scientific

inquiry in classroom instruction when teaching science disciplines at all levels and by

giving core ideas of engineering and technology the same status as those in other major

science disciplines" (NGSS, 2013, Appendix A). The Eight Science and Engineering

Practices in NGSS are identified below in Table 1. They are taken directly from

Appendix F of NGSS.

Table 1
Eight Science and Engineering Practices in the NGSS (NGSS, 2013, Appendix F, pp. 4-15)

Eight Science and Engineering Practices in the NGSS		
Practice	Title	Purpose
1	Asking Questions and Defining Problems	Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution.
2	Developing and Using Models	Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system.
3	Planning and Carrying Out Investigations	Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)— to those that emerge from students' own questions.
4	Analyzing and Interpreting Data	Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.

		Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures.
5	Using Mathematics and Computational Thinking	Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question.
6	Constructing Explanations and Designing Solutions	Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur. In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting

		among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.
7	Engaging in Argument from Evidence	The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose.
8	Obtaining, Evaluating, and Communicating Information	Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering.

As more and more states adopt NGSS, a need for teacher training and development also increases. Pre-service science teacher programs will evolve with the changing standards to produce teachers that are familiar and trained in the core principles of NGSS but there will also be significant change needed in the professional development of practicing teachers because ultimately the teacher needs to have strong content knowledge as well as a thorough understanding of the engineering design process to effectively deliver science instruction to their students. Vessel (2011) reviewed many studies conducted by individuals, groups and state governments across the nation to assess teacher professional development, and it generally boiled down to a few common points: 1) a lack of engineering knowledge impacts other areas of science, i.e. it decreases students' achievement level in science and technological literacy on the K-12 level, 2)

when teachers have low self-efficacy, it negatively impacts how they design their

curriculum for engineering, design, and technology as well as it lowers the teachers'

ability to deliver effective instruction, 3) teachers do not have the necessary math and

science skills to effectively teach engineering principles and thus leave out areas that are

critical to a student's overall understanding and development of engineering design

concepts, and 4) not keeping pace with the changes in science and technology also affects

how teachers view their subject matter and it lowers their self-efficacy to teach it

effectively (Vessel, 2011).

These findings are important and must be taken into consideration when putting

together the proper training and development programs for teachers because how

comfortable a teachers feels in his/her discipline impacts the learning outcome of

students. As Fraser-Abder eloquently stated,

> teachers need to feel that they have an adequate knowledge of science, can
> teach it without fear, are comfortable using science equipment in their
> classroom, and are interested in science and can pass on this interest to their
> students before they can be classified as good science teachers (Fraser-
> Abder, 1989, p. 561).

Engineering design self-efficacy is highly dependent on engineering experiences

(Carberry et al., 2010). This must be a component of any future professional

development experience for teachers. When teachers were involved in an on-going

professional summer institute with follow-up in the fall and spring conducted by Nugent

et al., they found that "teachers significantly increased their knowledge of engineering,

developed more positive attitudes towards technology, increased their self-efficacy in

using and developing technology-based lessons, and increased their confidence in

teaching math and science" (Nugent, et al., 2010, p. 17). These findings are significant because self-efficacy leads to an increased comfort level for the teacher in the classroom.

Stricker found in his research that "teaching strategies rely on the teacher's comfort with their ability to adapt to ambiguous and novel situations that can occur within open-ended problem solving which are characteristic of effective engineering curricula" (Stricker, 2011, p. 94). Cunningham concurred by stating, "when teachers understand concepts and are comfortable teaching them that is when they teach best" (Cunningham, 2007, p. 5). With these new standards, teachers who possess knowledge of disciplinary core ideas, scientific and engineering practices, and crosscutting concepts are no longer the ideal teacher, it is what is required to move science education in this country into the 21st century and beyond (NGSS, 2013).

METHODOLOGY

The purpose of this study was to survey in-service K-12 science teachers' preparedness for incorporating engineering design principles into their science curricula. This facet was the primary focus for this study because of the changing nature of science standards across the country. With the adoption of NGSS, there is an emphasis on science and engineering practices as one of three dimensions which has not been part of traditional science standards. As more and more states adopt these new standards, preparation of preservice teachers and professional development for practicing teachers must also evolve. Data will be viewed through two different lenses: whether the teacher teaches in a NGSS state and through grade bands.

Teacher surveys were sent out via 3 main routes: all National Science Teachers Association's (NSTA) listservs, all Connection Education's (CE) PLCs, and a Virginia Science Teacher's listserv. There were 199 participants involved in this study, 184 of which were K-12 science teachers representing 42 different states and 2 international locations (N=184). The teachers who attempted to complete the survey but answered no to the first question, Do you teach science?, were exited from the survey and thanked for their participation. This is how the number of responses for this survey changed from 199 originally to 184 ultimately. Each science teacher who answered yes to the first question completed a 30 question survey composed Likert style scaled responses and open ended questions. The survey was divided into three sections: demographic information, engineering and implementation, and research questions and was designed to address the following questions:

1) How well prepared are Science teachers to incorporate engineering design principles into their Science curricula?

2) How do teachers define the engineering process?

3) How relevant is engineering/engineering design to what a science teacher teaches?

4) Does professional development make a difference?

A copy of the survey form is included in Appendix A.

Overall, out of the 184 respondents, most were female teachers who were fully licensed with advanced degrees who taught physical sciences in high schools with greater

than 1000 students and had more than 16 years of service. About 40% were teachers

from NGSS states and there was a fairly even distribution of locations between rural,

suburban and urban.

This survey method was chosen because it is a very accurate, timely, and reliable

way to gather data and information about teachers' thoughts, attitudes, experiences and

preparedness when it comes to incorporating the engineering design process into their

science class(es).

Once teachers began the survey, they were asked about their demographics with

the first question asking about their licensure. The majority of teachers had full licensure

(Figure 2).

Are you fully licensed?
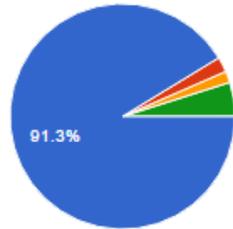
Yes	168	91.3%
No	4	2.2%
On a provisional license	3	1.6%
Other	9	4.9%

Figure 2. Are you fully licensed?

Next, teachers were asked their gender and about 75% were female with the rest being

male. Three teachers preferred not to state their gender. Teachers were asked to

categorize the grade level(s) they taught and the majority were high school teachers

grades 9-12 (Figure 3).

What grade level(s) do you teach (or closely match what you teach)?
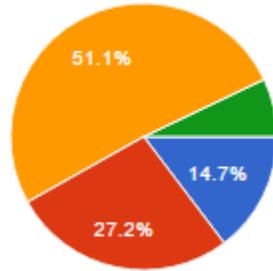
K-5	27	14.7%
6-8	50	27.2%
9-12	94	51.1%
6-12	13	7.1%

Figure 3. What grade level(s) do you teach (or closely match what you teach)?

The next two question that were asked are somewhat related and there was not a lot of difference in the answer distribution. Teachers were asked how many years they have been teaching science (Figure 4) and how many years all together they have taught school (Figure 5). The majority are veteran teachers with 16 + years of teaching experience.

How many years have you been teaching science?
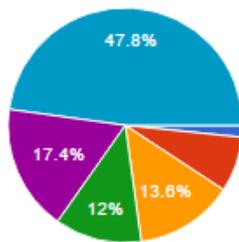
This is my first year	3	1.6%
1-3	14	7.6%
4-7	25	13.6%
8-10	22	12%
11-15	32	17.4%
16 +	88	47.8%

Figure 4. How many years have you been teaching science?

How many years have you been teaching all together?
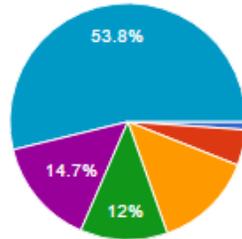
This is my first year	2	1.1%
1-3	9	4.9%
4-7	25	13.6%
8-10	22	12%
11-15	27	14.7%
16 +	99	53.8%

Figure 5. How many years have you been teaching all together?

Which best describes your educational level?
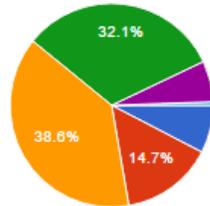
Bachelor's	14	7.6%
Some graduate school	27	14.7%
Master's	71	38.6%
Graduate school beyond a Master's	59	32.1%
Doctorate	12	6.5%
Other	1	0.5%

Figure 6. Teachers' educational level.

After that, teachers were asked about their education level (Figure 6). This was surprising data at first glance because of the numbers of teachers with advanced degrees. But after some more careful reflection, it made a little more sense because of where the respondents were coming from: NSTA listservs, CE PLCs, and a Virginia Science Teacher listserv. The people who receive and read these emails are really invested teaching professionals. As a result, my data may appear better than it would otherwise because of the somewhat selective nature of the respondents.

In the next phase of the demographic questions, teachers were asked about their teaching assignments, particularly about which discipline is their predominant area of

teaching. The distribution from greatest to least is Physical Sciences, Life Sciences and

Earth/Space Sciences (Figure 7).

Which category or categories of courses do you predominantly (more than 50%) teach each year?

Earth & Space Sciences	72	39.1%
Life Sciences	88	47.8%
Physical Sciences	101	54.9%
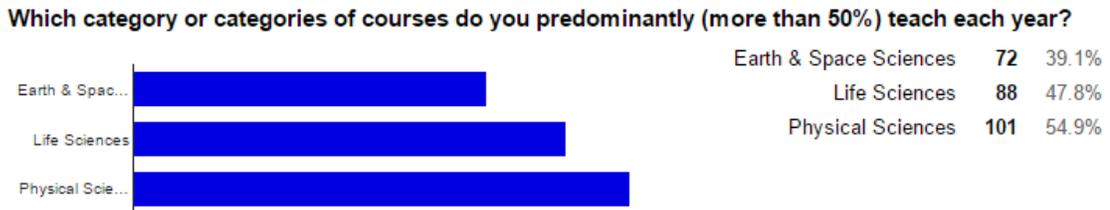
Figure 7. Categories of courses predominantly taught each year.

Teachers were surveyed to know how comfortable they felt teaching in their discipline

(Figure 8). Teachers felt very comfortable teaching in their discipline and the mean for

this question was 4.529.

How comfortable do you feel within your discipline?

Not very comfortable: 1	0	0%
2	0	0%
3	8	4.3%
4	70	38%
As comfortable as I could be!: 5	106	57.6%

Figure 8. How comfortable do you feel within your discipline?

Next, teachers were asked about the location of the school they teach in and its

student population size. The school location answers showed an excellent cross-section

of different school location types (Figure 9) and since the majority of teachers responding

were from the high school level, it was expected that the majority of student populations

reported were in excess of 1000 students (Figure 10).

How would you describe where your school is located?
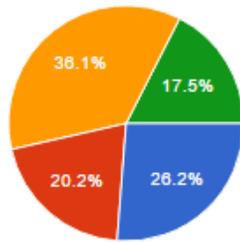
Large urban area	48	26.1%
Medium urban area	37	20.1%
Suburban area	66	35.9%
Rural area	32	17.4%

Figure 9. School Location.

Approximately how many students attend your school?
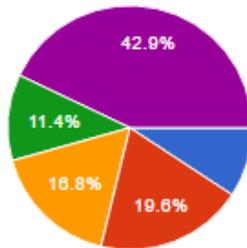
0-250	17	9.2%
251-500	36	19.6%
501-750	31	16.8%
751-1000	21	11.4%
1001 or greater	79	42.9%

Figure 10. Student Populations.

In the last question of the demographic section, teachers were asked whether they lived in a NGSS adopted state or not (Figure 11). They were also allowed to answer "I'm not sure" if they didn't know the answer to that question. Table 2 shows the adjusted results once the answers were able to be cross checked with the most current information on state adoptions of NGSS. This is an example of the limitations on self-reporting when being surveyed.

Has your state adopted the Next Generation Science Standards (NGSS)?
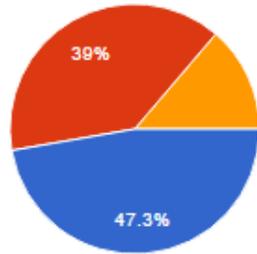
Yes	86	47.3%
No	71	39%
I am not sure	25	13.7%

Figure 11. Has your state adopted the NGSS?

Table 2
Adjusted Response Data for NGSS States

Verification and adjustment of NGSS adoption states with reported location						
Response	Before		After		Change	
Yes	86	47.3%	73	40.1%	- 12	- 7.2%
No	71	39%	109	60%	+ 37	+ 21%
I'm not sure	25	13.7%	0	0%	- 25	- 13.7%

The response data had to be adjusted because there were 19 teachers who responded "yes" when they were not in NGSS states, 22 said "I'm not sure" and they were not in NGSS states, 3 said "no" when they were in NGSS states, and 3 said "I'm not sure" and they were in NGSS states.

DATA AND ANALYSIS

In this section, data from the survey is analyzed through the lens of the research questions. The primary and sub questions were answered with the data collected and analyzed for patterns and trends as they relate to NGSS and grade bands.

Teachers were asked to respond to were about engineering and implementing engineering concepts in their science instruction. The first question asked was, "Do you

include engineering concepts in your science teaching?" and about 75% of the teachers

answered "yes" (Figure 12).

Figure 12. Do you include engineering concepts in your science teaching?

Teachers were asked whether they had college coursework or professional development

specifically in engineering (Figure 13) and if they had college coursework or professional

development in implementing engineering into their science curriculum (Figure 14). The

numbers were not very different from each other.

Figure 13. College coursework or professional development in engineering.

Have you had any Professional Development or college coursework on implementing Engineering into your science curriculum?

Yes **84** 45.7%
No **100** 54.3%

Figure 14. College coursework or professional development in implementing engineering into science curricula.

The follow up to that question was to rate how comfortable they felt including engineering concepts in their science class(es). The mean of 3.318 begins to reveal a connection between the level of professional development and level of comfort including engineering concepts in their science class(es) even though the majority were doing just that (Figure 15).

On a scale of 1-5, how comfortable do you feel including engineering concepts in your science class(es)?

I don't feel comfortable at all: 1	13	7.1%
2	31	16.8%
3	55	29.9%
4	53	28.8%
I am as comfortable as can be!: 5	32	17.4%
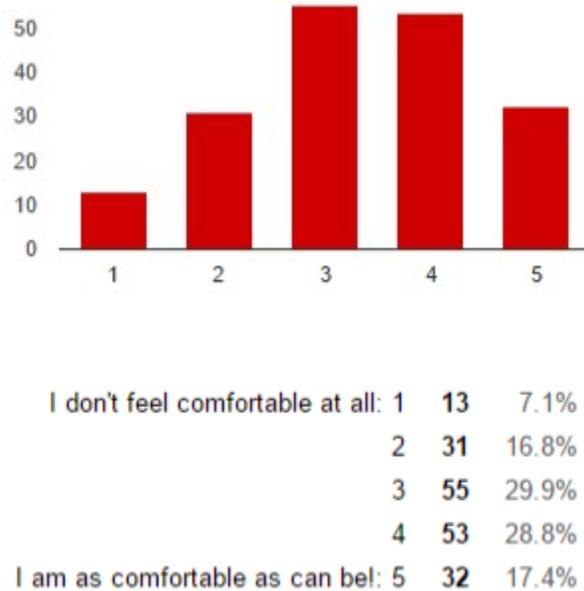
Figure 15. Level of comfort including engineering concept in your science class(es).

The final question in this section was to have teachers rate their willingness to learn how to include engineering concepts in their science class(es) under the assumption that teachers would not have to pay for that professional development (Figure 16). This caveat skewed the data somewhat because teachers rarely get to attend quality professional development at no cost.

On a scale of 1-5, how willing are you to learn how to include engineering concepts in your science class(es)? (assume that costs are covered)
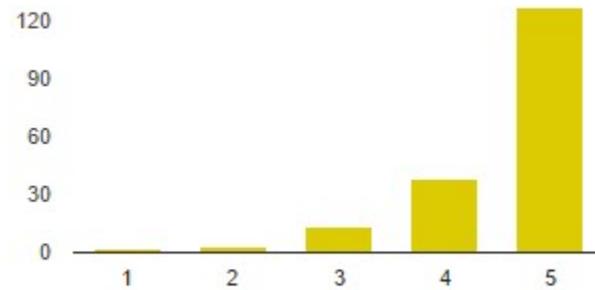
I'm not willing; I have no interest: 1	2	1.1%
2	3	1.6%
3	13	7.1%
4	38	20.8%
I am very willing; I would love to!: 5	127	69.4%

Figure 16. Willingness to learn how to include engineering concepts in your science class(es).

The data shows the overwhelming willingness of teachers to improve their craft and update their skill set for teaching, which is a clear indicator of an invested professional.

The last section of the survey focused on the research question surrounding relevancy of the engineering process in each of the 3 major science disciplines offered in high school: life science, earth/space science, and physical science. Teachers were asked questions about what engineers do, to name as many engineering fields as possible, and to describe the engineering design process in two sentences. Teachers were also surveyed for each discipline, responding to the question how relevant is engineering/engineering design to what a life, earth/space or physical science teacher teaches. Teachers rated their responses on a scale of 1-5 with 1 being not very relevant – "I don't see a connection" - and 5 being it is extremely relevant. After each separate

discipline related question was asked, teachers were asked to provide an example that related to the discipline in question (Table 7). Most teachers could provide a general idea of what engineers do. They also listed at least 3 different engineering fields but describing the engineering process was an area of weakness because not enough detail was given to adequately describe the entire process (Table 3). Tables 4 and 5 show the breakdown of the responses and sends them through the 2 lenses that were mentioned earlier: teachers who live in NGSS states and by grade band.

Table 3
How Do Teachers Define the Engineering Process?

	Count	Percentage
General definition	157/184	85%
3 Themes:		
Problem Solving	146/184	79%
Repeated Trials/Iterations	122/184	66%
Design Improvement/Modification	111/184	60%
All 3 themes	95/184	52%

Table 4
How Do Teachers Define the Engineering Process (Through NGSS Lens)?

	Count	Percentage
All 3 themes	95	
Have had college coursework or PD (out of the	59/95	62%
NGSS teachers	43/95	45%
Both NGSS teachers & have had college coursework	26/95	27%

The percentage of teachers who had all 3 themes in their definition closely matched the

percentage of teachers who have had professional development. Teachers providing a

complete definition and living in NGSS states, their percentages were disproportionately

low compared to their population size.

Table 5
How Do Teachers Define the Engineering Process (Through Grade Band Lens)?

	Totals	K-5		6-8/6-12		9-12	
Respondents	184	27	15%	63	34%	94	51%
All 3 themes	95	20	74%	35	56%	40	43%
PD or College courses	59	16	59%	22	35%	21	22%
NGSS State	43	7	26%	19	30%	17	18%
Both NGSS & PD	26	6	22%	11	17%	9	10%

K-5 teachers had the highest percentages in every category except NGSS state. Again

this may have been skewed simply by the population surveyed but it still was

significantly higher assuming that the rest of the middle school and high school teachers

came from that same population of invested professionals belonging to NSTA.

Tying in the ideas of professional development and defining accurately and

completely what engineering design revealed another layer of information which showed

some disturbing numbers (Table 6). The data showed the "yes" and "no" responses to the

two different types of professional development, which teachers answered "yes" or "no"

to both questions, and then quantified how much professional development teachers have

had depending on their responses. On the next level, the data showed how much

professional development teachers have had from NGSS states with the same breakdown

of the two types of professional development. It points to a real and current need for

professional development.

Table 6

Professional Development and Connections to NGSS State Teachers

	"Yes" response	Percentage	"No" response	Percentage
College coursework or professional development in engineering	80	43.5%	104	56.5%
College coursework or professional development in implementing engineering concepts into science class(es)	84	45.7%	100	54.3%
Answered yes to both	63	34%	X	X
Answered yes to both & from NGSS state	26	35%	X	X
Answered no to both	X	X	85	46%
Answered no to both & from NGSS state	X	X	32	43%

The next segment of this section focused on how relevant teachers rated engineering design to their teaching discipline and shows the life science relevancy scale with a mean of 3.925 (Figure 17). There is a consensus that engineering design is relevant to what the life science teacher teaches.

How relevant is engineering/engineering design to what a Life Science teacher teaches?
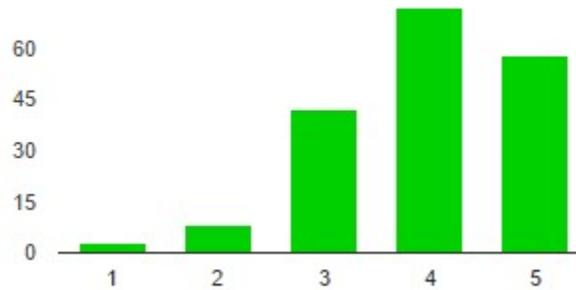
Not very relevant; I don't see a connection: 1	3	1.6%
2	8	4.3%
3	42	22.8%
4	72	39.1%
It is extremely relevant: 5	58	31.5%

Figure 17. How relevant is engineering/engineering design to what a life science teacher teaches?

There is a stronger consensus that engineering design is relevant to what the earth/space science teacher teaches and it shows the earth/space science relevancy scale with a mean of 4.461 (Figure 18).

How relevant is engineering/engineering design to what an Earth & Space Science teacher teaches?
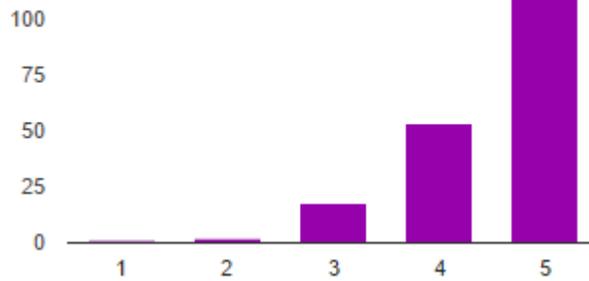
Not very relevant; I don't see a connection: 1	1	0.5%
2	2	1.1%
3	18	9.8%
4	53	29%
It is extremely relevant: 5	109	59.6%

Figure 18. How relevant is engineering/engineering design to what an earth/space science teacher teaches?

How relevant is engineering/engineering design to what a Physical Science teacher teaches?
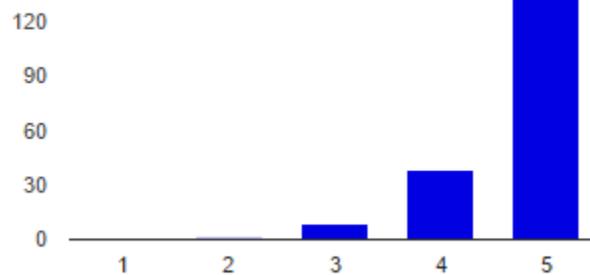
```
Not very relevant; I don't see a connection: 1      0      0%
                                           2      1      0.5%
                                           3      9      4.9%
                                           4     38     20.8%
            It is extremely relevant: 5    135     73.8%
```

Figure 19. How relevant is engineering/engineering design to what a physical science teacher teaches?

There is the strongest consensus that engineering design is relevant to what the physical science teacher teaches and it shows the physical science relevancy scale with a mean of 4.679 (Figure 19). The most common themes of engineering examples are listed in order (top to bottom) from greatest to least responses (Table 7).

Table 7
Common Themes of Engineering Examples in Each Science Discipline

Life Science	Earth/Space Science	Physical Science
prosthetics	rocketry/spacecraft	equipment/machines
environmental	space equipment	energy
medical	environmental	chemistry
genetic/GMO	energy	roller coasters
agriculture	instrumentation/technology	safety
equipment/technology	natural disasters	bridges
	satellites	pharmaceutical/medical
	ocean/marine exploration	environmental
		sound

For the life science example, 18 teachers (9.8%) provided no example and 6 of those

teachers (33.3%) were from NGSS states. Thirty-four teachers (18.5%) provided no

earth/space science example and 10 of those teachers (29.4%) were from NGSS states.

Lastly, 46 teachers (25%) provided no physical science example and 16 of those teachers

(34.8%) were from NGSS states.

Taking all of this data into consideration and connecting it with the study

questions, there are a number of claims that can be made.   Based on the responses to the

professional development questions, teachers are not well prepared to incorporate

engineering design into their science curricula. Less than half of the teachers have had

training in engineering or implementing engineering concepts and only 52% of the total

number of teachers included all 3 themes in their response to the engineering design

process question. When looked at through the NGSS/non-NGSS lens, there was not

much difference between them. One would think that teachers living in states that have

adopted NGSS would have higher rates than non-NGSS states but that is not the case

here. Looking at it from a K-5, middle school and high school band lens, the numbers are

a bit more meaningful. Surprisingly, the K-5 group had the highest percentage of correct

engineering process design definitions with 74% of the total number of teachers giving a

thorough and complete answer. It decreased as the grade levels went up, with high

school teachers offering the fewest correct responses (43%).

When teachers were asked about the relevancy of engineering design on each

science discipline taught, most teachers considered it to be relevant regardless of the

discipline. The trend noted was an increase in relevancy when viewing it from the life

science to earth/space science and ultimately physical science. These data were not unexpected. Teachers were able to provide engineering examples in most cases. Teachers who did not provide an example were at about the same rates regardless of NGSS or not NGSS teachers.

The last research question involved whether professional development makes a difference. Clearly, there is a strong correlation between professional development and understanding as well as being able to articulate what the engineering design process is. The K-5 teachers had the most professional development and also had the highest percentage of correct engineering design process answers. The same pattern holds true when looking at professional development and NGSS states together. The K-5 teachers are better equipped to implement engineering concepts into their science curricula. Even though comparing each of these groups with each other, there seems to be a light at the end of the tunnel overall, a desperate need for professional development remains because more than half of some of the most motivated and seasoned teachers have not received it.

INTERPRETATION AND CONCLUSION

Focused, ongoing professional development of pre-service and currently practicing teachers is the key to ushering in NGSS or any other science standards properly. As Cunningham (2007) stated,

> ... it is not surprising that most science teachers, like the United States' population in general, lack a firm understanding of engineering practices, uses, and concepts. Few teachers learned about this discipline while they were in school. Therefore, for a teacher to feel comfortable integrating it into their class will generally require that they engage in teacher professional development that focuses on engineering concepts (subject matter knowledge) and pedagogical strategies to teach this discipline (pedagogical content knowledge) (Cunningham, 2007, p. 3).

So far, 17 states have officially adopted NGSS along with the District of
Columbia but there are 23 more states discussing adoption. Professional development
has not kept pace with all of the changes that have happened with science standards over
the last 15-20 years. Implementing scientific inquiry into the classroom, as it competes
with instructional time for end-of-year assessments, has not taken a complete foothold in
classrooms across the country. Now as the NGSS adds another dimension with the
emphasis on engineering practices, more competition for already stretched instructional
time is added to the educational mix and students, for the most part, still do not have the
requisite science skills to do inquiry, especially on the high school level. There is also a
lag between when NGSS adoption occurs and when training and development occur
which leaves a gap for many teachers who may not be proficient in engineering design to
delay implementation, or not implement altogether, the standards properly into their
instruction. It has been shown repeatedly throughout the literature that teachers who do
not feel comfortable with content will not be as effective as teachers who do. This
research corroborates that assertion on several levels: 1) teachers' inability to define the
engineering process completely, 2) the lack of teacher preparation to integrate
engineering concepts into the science curricula, 3) the lack of professional development
the teachers have experienced, and 4) the teachers' self-report of how many are
integrating engineering concepts into their instruction and their level of comfort doing so

In summary, the group of teachers who responded to the survey was the best and
the brightest out there. They were mostly highly educated, veteran teachers who felt
comfortable in their teaching discipline but who have not had their professional

development needs met to remain on the cutting edge of science teaching as more and

more states adopt NGSS, but are more than willing to learn and grow as professionals.

Table 8
Research Questions and Answers

Research Question	Answer
How well prepared are Science teachers to incorporate engineering design principles into their Science curricula?	not very well
How do teachers define the engineering process?	most could generally define it but few can provide a complete, detailed definition
How relevant is engineering/engineering design to what a science teacher teaches?	most saw relevancy and could provide an appropriate example
Does professional development make a difference?	yes but it has to be ongoing with more than one exposure and must include engineering experiences to increase the self-efficacy of the individual teacher to truly make a difference in the classroom

Professional development needs to take a front seat alongside the adoption of

NGSS so that the needs of everyone (teachers, students, communities, businesses, and

government entities) are met simultaneously.

This study was just a starting point - a baseline of data to continue researching

these important questions. Recommendations for other things to think about in the future

include whether or not professional development be offered by a district, by teacher

initiative, by school or by some other means. As Nugent, et al. (2010) stated, the type of

professional development needs for teachers must include several parameters to be

effective in the teachers' classrooms: 1) adequate time to develop lesson plans (as in a

summer institute), 2) peer teacher support and guidance, 3) focus on real-world

engineering problems and solutions, 4) ongoing support of all participants in the year following a summer institute (i.e. peer teachers, faculty and graduate students), and 5) collaboration between Education and Engineering faculty in development and implementation of teacher professional development.

VALUE

This project exposes the real and current need teachers have for professional development. As invested professionals, maintaining cutting edge knowledge and the ability to integrate that into our science class(es) is critical if we are to improve our standing in the world when it comes to science education and to train our students to be the critical thinkers we want them to be in order to maintain the integrity of our society. Cunningham (2007) said it best, "educators teach best when they understand a concept and feel comfortable teaching it. A focus on the engineering design process also supports treating teachers as professionals with expertise" (Cunningham, 2007, pp. 4 and 5)

This study had a great impact on my professional practice as well. I currently live in a non-NGSS state and am like most of the teachers who responded to the survey. I realized that I needed to make updates and changes to my own knowledge base and teaching skills. I now see an opportunity where I can become a leader within my school and profession by embracing, and not fearing, NGSS.

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APPENDICES

APPENDIX A

TEACHER SURVEY QUESTIONS

Capstone Project Survey for Teachers

By your willingness to complete this survey, you are agreeing to participate in this research project. All responses are anonymous and only aggregate data will be reported. Participation is always voluntary.

* Required

1. **Do you teach Science?** * *Mark only one oval.*

   ◯ Yes *Skip to question2.*

   ◯ No *Stop filling out this form.*

Basic Demographic Information

2. **In which state do you teach?** *

   ....

3. **Are you fully licensed?** * *Mark only one oval.*

   ◯ Yes

   ◯ No

   ◯ On a provisional license

   ◯ Other: ....

4. **What is your gender?** * *Mark only one oval.*

   ◯ Fema

   ◯ le

      Male

   ◯ Prefer not to answer

5. **What grade level(s) do you teach (or closely match what you teach)?** *

Mark only one oval.

( ) K-5

( ) 6-8

( ) 9-12

( ) 6-12

6. **How many years have you been teaching science?** * *Mark only one oval.*

( ) This is my first year

( ) 1-3

( ) 4-7

( ) 8-10

( ) 11-15

( ) 16 +

7. **How many years have you been teaching all together?** * *Mark only one oval.*

( ) This is my first year

( ) 1-3

( ) 4-7

( ) 8-10

( ) 11-15

( ) 16 +

8. **Which best describes your educational level?** *

Mark only one oval.

( ) Bachelor's

( ) Some graduate

( ) school Master's

( ) Graduate school beyond a

( ) Master's Doctorate

( ) Other: ....

9. **Which category or categories of courses do you predominantly (more than 50%) teach each year?** *

Check all that apply.

- [ ] Earth & Space Sciences
- [ ] Life Sciences
- [ ] Physical Sciences

10. **How comfortable do you feel within your discipline?** *

Mark only one oval.

	1	2	3	4	5	
Not very comfortable	◯	◯	◯	◯	◯	As comfortable as I could be!

11. **How would you describe where your school is located?** * *Mark only one oval.*

- ◯ Large urban area
- ◯ Medium urban area
- ◯ Suburban area Rural
- ◯ area

12. **Approximately how many students attend your school?** * *Mark only one oval.*

- ◯ 0-250
- ◯ 251-500
- ◯ 501-750
- ◯ 751-1000
- ◯ 1001 or greater

13. **Has your state adopted the Next Generation Science Standards (NGSS)?** *

Mark only one oval.

- ◯ Yes No
- ◯ I am not sure
- ◯

Engineering & Implementation

Questions about your specific teaching experience:

14. **Do you include engineering concepts in your science teaching?** * *Mark only one oval.*

( )   Yes

( )   No

15. **Have you had any Professional Development or college coursework in Engineering?** *

    Mark only one oval.

( )   Yes

( )   No   *Skip to question 17.*

Types of Professional Development or college coursework in Engineering

16. **Please describe the Professional Development or college coursework in Engineering that you have had.** *

....

....

....

....

....

Back to Engineering & Implementation

17. **Have you had any Professional Development or college coursework on implementing Engineering into your science curriculum ?** *

    Mark only one oval.

( )   Yes

( )   No   *Skip to question 19.*

Types of Professional Development or college coursework on implementing Engineering into your science curriculum

18. **Please describe the Professional Development or college coursework that you have had on implementing Engineering into your science curriculum. ***

....

....

....

....

....

Last section on Engineering & Implementation

19. **On a scale of 1-5, how comfortable do you feel including engineering concepts in your science class(es)? ***

Mark only one oval.

	1	2	3	4	5	
I don't feel comfortable at all	⬭				⬭	I am as comfortable as can be!
		⬭	⬭	⬭		

20. **On a scale of 1-5, how willing are you to learn how to include engineering concepts in your science class(es)? (assume that costs are covered) ***

Mark only one oval.

	1	2	3	4	5	
I'm not willing; I have no interest	⬭	⬭	⬭	⬭	⬭	I am very willing; I would love to!

Research Questions

21. **What do engineers do?** *

....

....

....

....

....

22. **Name as many engineering fields as you can think of:** *

....

....

....

....

....

23. **How relevant is engineering/engineering design to what a Life Science teacher teaches?** *
Mark only one oval.

	1	2	3	4	5	
Not very relevant; I don't see a connection	◯	◯	◯	◯	◯	It is extremely relevant

24. **Can you provide an engineering example that relates to Life Science?**

....

....

....

....

....

25. **How relevant is engineering/engineering design to what an Earth & Space Science teacher teaches?** *

Mark only one oval.

	1	2	3	4	5	
Not very relevant; I don't see a connection	◯	◯	◯	◯	◯	It is extremely relevant

26. **Can you provide an engineering example that relates to Earth/Space Science?**

_____

_____

_____

_____

_____

27. **How relevant is engineering/engineering design to what a Physical Science teacher teaches?** *

Mark only one oval.

	1	2	3	4	5	
Not very relevant; I don't see a connection	◯	◯	◯	◯	◯	It is extremely relevant

28. **Can you provide an engineering example that relates to Physical Science?**

_____

_____

_____

_____

_____

29. **How do you describe the engineering design process?** *

....

....

....

....

....

30. **How would you describe the engineering design process if you had to summarize it in ONLY 2 sentences?** *

....

....

....

....

....

31. **If I can contact you to follow up on any of these questions, please include your e-mail address. Thank you for participating!**

....

....

....

....

....