



Interests and Needs of Secondary Science Educators Regarding Professional Development on Engineering Standards (Fundamental)

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Abstract

Many secondary-level science educators across America are now or will soon be required to address engineering curriculum in their science courses. This is in response to calls from the National Research Council and others to increase engineering exposure in K-12 settings. Science teachers in the 18 states that have adopted the Next Generation Science Standards are already expected to address the engineering themes and concepts that have been integrated into these standards. Though science educators may now be expected to teach engineering, few have any training in the field, and it is unknown whether or not they are already prepared to provide effective engineering instruction. Recent survey work in the state of Utah has investigated science teachers' perceptions of their preparedness to teach engineering. The results of this study indicate a spectrum of indicated preparedness. Building and extending upon that work, this research looks to investigate secondary science educators' self-assessment of their preparedness to teach engineering. A new survey was developed to assess science educators' confidence in integrating engineering content knowledge into their science classes. Specifically, the survey includes questions about confidence in basic engineering content knowledge areas from Statics, Strength of Materials, and Material Science. The survey also assessed the benefit educators thought professional development in engineering would provide to them as they develop engineering content for their classes. Completed survey responses were received from 338 secondary science teachers across 20 states, and analysis has been started to determine respondents' readiness to address engineering content and their desire to participate in related professional development. The data indicate relatively low confidence in engineering content, but a widespread desire for professional development in this area.

Introduction

Though students have been studying and learning engineering for centuries, this has traditionally been limited to education at the university level. However, more recently there has been a push to incorporate engineering design processes and content in K-12 educational environments.

In 2010, the National Academy of Engineering released *Standards for K-12 Engineering Education?* [1] which discusses how standards for engineering education would be most effectively introduced into a K-12 setting. The authors concluded that engineering standards would be best if incorporated into standards for common related fields, such as math and science. In 2012, the National Research Council (NRC) [2] developed this idea further by publishing a framework for science standards which heavily incorporate engineering. In 2013, the Next Generation Science Standards (NGSS) [3] were released which directly implement the ideas from the 2012 NRC publication. These standards have been adopted 18 states so far [4], and several other states have chosen to reevaluate and redesign their own standards based on the new concepts in the NGSS. The NGSS not only include standards focused on engineering within the battery of science standards, but also incorporate engineering as one of four crosscutting concepts that thematically run throughout the entire set of standards.

Bringing engineering education to the K-12 level presents many new challenges. Quality K-12 engineering education must be defined, key topics and competencies must be identified, teachers must develop expertise, content must be made developmentally appropriate, and assessment methods must be created. Tamara Moore and her colleagues have made significant progress towards the definition aspect of this challenge by developing a research-based framework that outlines key indicators that describe quality engineering education [5]. Also, the NGSS have begun to identify relevant competencies by articulating standards for engineering education within the context of K-12 science classes. This work focuses on the task of developing teachers' expertise in engineering as a subject they can effectively teach.

Many professional development programs have been created to train educators in engineering, as reviewed in [6], however few programs have been intentionally developed to align with the articulated need of educators and established principals of engineering education. To have the greatest impact, the expertise teachers develop should directly correspond to principles of effective engineering education. One such principle is the application of relevant math and science to engineering design problems. Moore identifies this principle as the second of nine key indicators in the framework for quality engineering education, stating that "engineering education at the K-12 level should emphasize this interdisciplinary nature including the integration of these areas [math, science, and engineering knowledge]. Students should have the opportunity to apply developmentally appropriate mathematics or science in the context of solving engineering problems." The National Research Council, in *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* also described this principle as the second of three general principles for engineering education. According to this NRC report, "engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills" [7].

Though the importance of applying math and science to engineering has been recognized as fundamental, its implementation is often more difficult. Though a teacher may find, study, and teach a model of the engineering design process without much difficulty, integrating relevant mathematical and scientific concepts into the practice of engineering in an authentic way requires more depth of knowledge in the engineering application studied. For example, a teacher may challenge his/her students to build a bridge to meet certain standards. This classic engineering design task will require students to engage in the design process by analyzing requirements, developing ideas, testing the product, and iterating designs. However, students may still not effectively learn to apply math and science to this engineering problem unless concepts such as tension, compression, equilibrium, stress, strain, or mechanical behavior of materials are also introduced. These concepts require a depth of engineering content knowledge that most science teachers have not been trained in.

Given the importance of engineering content knowledge to effective engineering education, this work looks to understand the need and desire among secondary science teachers to develop more thorough content knowledge in engineering topics.

Methods

A survey instrument was developed to measure the need and desire of science educators for

engineering training. The survey was based on similar work conducted by Ames [8], that surveyed science teachers within Utah to assess preparedness to teach engineering design. Ames' survey was modified to focus more heavily on engineering content knowledge, although some of the questions on engineering design and overall instruction were retained.

The instrument in this study consisted of 33 questions regarding teachers' confidence in addressing engineering material and the benefit they felt they would receive from varying aspects of professional development in engineering, as well as 13 questions to establish sample characteristics of respondents such as gender, subject taught, etc. The core of the survey (21 questions) focused on specific engineering topics from Statics, Strengths of Materials, and Material Science. These particular topics were chosen because of their broad and fundamental application across several disciplines of engineering. The majority of collegiate engineering students studying Mechanical, Civil, or Structural Engineering will be required to take courses in these areas near the beginning of their program, and will continue to use these concepts throughout their training and careers.

Respondents were asked "Which of the following engineering mechanics topics do you feel prepared and confident to develop and teach in your science courses?" for a list of 17 engineering topics. Seven topics came from material in Engineering Statics, 6 came from Strengths of Materials, and 4 from Material Science. Participants responded to each individual topic that they were either "Prepared", "Confident," or had "No idea" how to teach the topic. Responses were coded numerically as 3, 2, and 1 respectively.

Participants were then asked how much benefit they thought they would receive from professional development on the three topic categories described above. Responses were given as High, Medium, or Low, and coded as 3, 2, and 1, respectively. Respondents were also asked if they felt they would benefit from professional development in engineering overall, on a 7-point Likert scale ranging from "I disagree a great deal that I can benefit..." to "I agree a great deal that I can benefit...". These values were coded from 1 through 7 respectively.

The survey was distributed to 2520 science teachers in 20 states, and 580 responded. Analysis was limited to respondents who completed the survey and agreed to participate in research, which brought the total sample size used in the analysis down to 338. Basic analysis was performed and the response described is reported in terms of the percentage of total participants ($n = 338$) that responded with a given answer. No statistical analyses were performed to evaluate the statistical significance of these results in comparison to the population at large.

Respondents represented a variety of school settings ranging from rural to urban, more than 15 different science topics, AP, honors, IB, and regular education courses, and a nearly even distribution of male and female teachers. Only 25% of respondents reported that they had participated in engineering training or coursework, ranging from week long projects to engineering masters degrees.

Results

An overwhelming majority of participants indicated that they could benefit from professional

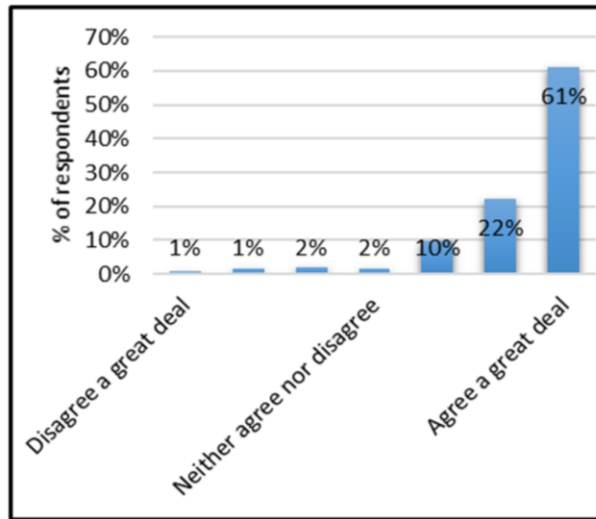


Fig. 1 Histogram of participants' response to the survey item: "I can benefit from professional development that includes basic engineering knowledge found in engineering mechanics courses such as Statics, Strengths of materials, and Material science."

development based on engineering content knowledge, as seen in Fig. 1. Ninety-three percent of respondents agreed with the statement "I can benefit from professional development that includes basic engineering knowledge found in engineering mechanics courses such as Statics, Strengths of materials, and Material science." This result alone is a compelling argument for the creation and implementation of professional development programs that emphasize engineering content knowledge. Even one respondent who stated "I don't like engineering classes. If I did, I would be an engineer." agreed a great deal with this item. These results demonstrate that many science teachers recognize the value of engineering content knowledge for their educational practice, even though it may not be a field they personally appreciate.

As confidence and anticipated benefit were broken down into specific areas, patterns emerged between the areas addressed in the survey. First we look at the 17 questions assessing teachers' confidence to develop and teach engineering curriculum. After responses had been coded numerically, the responses of each participant were averaged within each overall engineering topic (Statics, Strengths of Materials, or Material Science) to give just three response values for each participant. Average responses were binned into 5 levels representing average numerical responses of 1 to 1.39, 1.4 to 1.79, 1.8 to 2.19, 2.2 to 2.59, and 2.6 to 3. A histogram of these data is shown in Fig. 2. Teachers' confidence in developing and teaching Statics concepts in their science courses was relatively evenly distributed across the spectrum, however teachers' confidence in integrating concepts from Strengths of Materials and Material Science was heavily skewed, indicating that most science teachers do not feel prepared to address this material in their classes.

Table 1 summarizes the responses to questions about the level of benefit that professional development would provide to respondents. Overall, most teachers anticipated meaningful benefit from professional development across all three engineering topics. In particular, more than half of respondents indicated that they would receive a high level of benefit from professional development in Strengths of Materials and Material Science concepts.

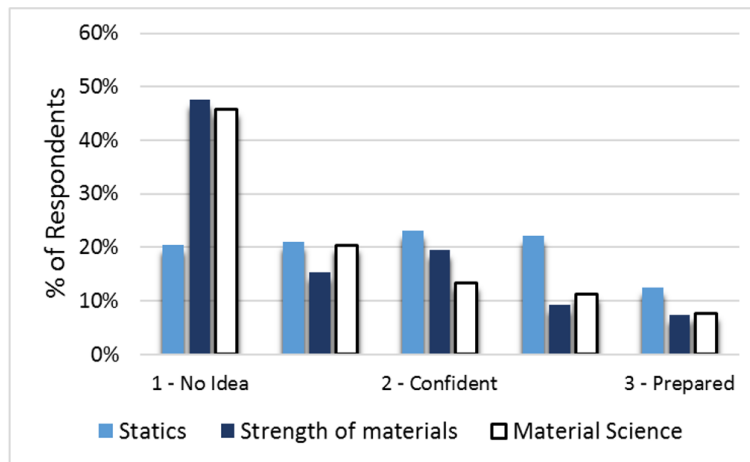


Fig. 2 Histogram of participants’ response to the survey item: “Which of the following engineering mechanics topics do you feel prepared and confident to develop and teach in your science courses: Engineering Statics, Mechanics (sic) of Materials, and Material Science?”

Table. 1 Percentages of respondents who anticipated high, medium, and low benefit from from the professional development topic listed in response to the question “How much benefit do you think the following professional development topics would provide for you towards developing engineering content for your science course?”

	High	Medium	Low
Basic Statics concepts Vectors, forces, moments, equilibrium, friction, analysis of structures	38%	38%	25%
Strength of material concepts Internal forces, Stress and strain, Tension and Compression, Torsion, Bending and shear	54%	33%	13%
Material science concepts Hook’s Law, stress-strain relationship, types of failure, elastic/plastic behavior	53%	33%	14%

In both the analyses of confidence and potential benefit, Statics stands out when compared to both Strengths of Materials and Material Science. More educators responded with a high confidence to teach Statics concepts, while fewer anticipated a high benefit from training in it. This may be due to the fact that Statics has a greater content overlap with traditional content of high school physics than the other topics, and thus more science educators are already familiar with it.

Conclusions and Future Work

The data presented in this paper demonstrate that large numbers of secondary science educators feel that professional development programs in engineering content knowledge can significantly benefit their ability to integrate engineering into their classes, as seen in Figure 1. Though science teachers may already understand a definition or model for engineering design, they recognize their weakness in engineering content knowledge. Based on this, educators are receptive to

developing this knowledge in order to improve their ability to implement authentic engineering concepts in their classes. Also, the differences in confidence and preparedness levels between various engineering mechanics topics provide important information about the current state of science teachers as relates to engineering instruction.

These conclusions serve as a foundation and justification for future work that will create professional development programs to better prepare teachers to address engineering standards. Because of the NGSS and other engineering standards that have been brought into K-12 science education, it is important that science educators improve their skills and confidence in delivering engineering content to their students, and educators are largely receptive to related training. Also, understanding the current state of teachers' preparation and needs provides a guide for the design of future professional development programs. For example, if a professional development program targeting engineering mechanics topics is created, it may be best served by taking advantage of educators' relative confidence in Statics, while building stronger content knowledge in Strengths of Materials and Material Science.

Since understanding teachers' current knowledge and confidence is important to the design of professional development, future work may also continue to assess teachers' current preparedness with a focus on foundational engineering concepts not addressed in this work. While the questions asked in this work centered around engineering mechanics topics, it would be informative to also gather similar data on topics that are foundational to engineering disciplines such as electrical, chemical, software, or others.

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Appendix - Survey Questions

The survey described in this paper consisted of the questions listed below. Most responses were on Likert-style scales though several were adapted to better fit the question.

- In engineering there is never just one single correct solution to a design challenge.
- Success in science and scientific endeavors can often be focused on a targeted goal of thoroughly explaining a phenomena.
- Success in engineering and engineering endeavors is focused on a targeted goal of creating a solution benefiting the public that is derived with the most economical means
- I feel confident enough in my foundational engineering knowledge levels to be able to develop and deliver engineering content focused on applications that satisfy engineering standards in the Next Generation Science Standards (NGSS).
- I feel confident in being able to answer most of my students' engineering focused questions in a science class.
- I feel confident in teaching engineering topics to address authentic engineering problems.
- Thinking about the design cycle, I feel confident beginning with a recognized need or desire and then developing the appropriate questions that define the engineering problem.
- I feel confident in using modeling or simulations to analyze elements of engineering problems.
- I feel confident in using mathematical and computational representations for engineering purposes.
- For the following activities, I feel confident referencing engineering knowledge/principles to enhance my engineering teaching.
 - Expressing novel ideas, orally and in writing
 - Use of tables, graphs, drawings, or models
 - Engaging in extended discussions with peers
 - I can benefit from professional development that includes basic engineering knowledge found in engineering mechanics courses such as Statics, Strengths of Materials, and Material Science.
- Please rate the following aspects of professional development that you feel may benefit your ability to teach engineering topics in your science class? (Please select all that apply and the extent to which you think they are useful)
 - Incorporating engineering content into required science standards
 - Content knowledge about engineering disciplines and the types of work they engage in.
 - Instruction on the use of engineering knowledge and technology in the classroom.
 - Lesson plan ideas incorporating engineering principles in authentic engineering problems.
 - Training on the engineering design process
 - Instruction on engineering analysis and design that is informed by appropriate engineering equations and methods
 - Ready access to one or more expert teachers in the field of engineering
 - Networking and collaboration with other science teachers
- Which of the following engineering mechanics topics do you feel prepared and confident to develop and teach in your science courses: (Please mark the topics that apply)

- Engineering Statics
 - Vector and scalar quantities
 - Vector operations
 - Forces, Moments, friction
 - Equilibrium / Newton's First Law
 - Analysis of truss components for magnitudes of tension or compression
 - Shear and bending moment diagrams
 - Centroid and moment of inertia
- Mechanics of Materials(sic)
 - Internal forces, External Forces
 - Stress and strain
 - Axial loading (tension and compression)
 - Torsion
 - Bending and shear
 - Calculate deflection of beams
- Material Science
 - Mechanical behavior of materials
 - Types of failure, yield, fracture
 - Hook's Law (sic), stress-strain relationship
 - Elasticity and plasticity
- How much benefit do you think the following professional development topics would provide for you towards developing engineering content for your science course? (Select all that apply).
 - Basic Statics concepts (vectors, forces, moments, equilibrium, friction, analysis of structures)
 - Strength of material concepts (Internal forces, Stress and strain, Tension and Compression, Torsion, Bending and shear)
 - Material science concepts (Hook's Law, stress-strain relationship, types of failure, elastic/plastic behavior)
 - Developing lesson plans that incorporate engineering principles/material to address authentic engineering problems.
- Are you currently teaching one or more science classes?
 - If yes, would you please list them:
- Have you taught science courses previous to receiving this survey?
 - If yes, would you please list them:
- How many years have you been teaching?
- How many years have you been teaching science?
- Have you ever taken any engineering courses offered by a university or college?
 - If yes, would you please list those engineering courses?
- Have you ever taken any supplemental engineering education training such as Project Lead the Way?
 - If yes, would you please list the name of the training?
- In what areas do you currently hold a teaching endorsement? (Select all that apply)
 - Physics; Chemistry; Physical Science; Technology and Engineering; Earth Sciences; Environmental Science; Geography; Middle Level Science; Biological Science; Other.

- Would you be willing to attend sponsored and funded professional development training at Utah State University to learn and develop engineering curriculum to enhance your existing science curriculum and to address the new engineering standards?
- What is your current gender identity?
- What permanent population estimate best reflects the area of the school you teach in?
- What permanent population estimate best reflects the area you currently reside in?