Assessing Teachers' Experiences with STEM and Perceived Barriers to Teaching Engineering

Sarah Marie Coppola, Tufts Center for Engineering Education and Outreach

Sarah Coppola is a graduate student in Human Factors Engineering at Tufts University. Prior to attending Tufts, Sarah worked as a reliability engineer and completed an AmeriCorps service year teaching in an engineering magnet high school in Paterson, NJ. She draws upon her diverse interests in design, teaching, and social justice in her research work in physical ergonomics and engineering education at the Center for Engineering Education and Outreach (CEEO). Sarah earned a Bachelor's Degree in Mechanical Engineering and Engineering Design from Northwestern University.

Mr. Leonardo Andres Madariaga, Tufts University Center for Engineering Education and Outreach / Federico Santa Maria Technical University

Leonardo Madariaga is a graduate student in the Center for Engineering Education and Outreach (CEEO) at Tufts University in Medford, MA. He graduated as a Product Design Engineer in 2006 from Federico Santa Maria Technical University (UTFSM) in Chile. Currently he is a M.S. student in Human Factors Engineering at Tufts. His primary interest is the generation of physical and digital environments that can foster design and creativity in engineering education. He has seven years of experience in teaching engineering undergraduates design methods and guiding them in project based courses at UTFSM in Chile, where he also worked as a product innovation consultant for several small companies.

Marya H Schnedeker, Center for Engineering Education and Outreach, Tufts University

Marya Schnedeker is a M.S. student at Tufts University in the Human Factors Engineering program. Her research focus is instructional design. She is currently researching methods of training novice users on CAD software and 3D printers.

The Assessing Teachers' Experiences with STEM and Perceived Barriers to Teaching Engineering (RTP-1)

Abstract

The next generation science standards (NGSS) call for all K-12 students to participate in engineering experiences. This will be a new subject area for many schools in the U.S. Teachers receive training to teach science and math, but most elementary and middle school teachers have not received engineering or technology education training. As the push for incorporating more STEM into K-12 increases, it is important to understand teachers' attitudes and experiences related to engineering and STEM at the K-12 level. The Novel Engineering Project (formerly Integrating Engineering and Literacy Project) recently surveyed 70 U.S. elementary and middle school teachers in 15 states to explore teachers' experiences with teaching engineering as well as their opinions about including more engineering in K-8 classrooms. The survey analysis accounted for differences in location, years of experience, and type of school. Conflicting external pressures and a lack of training emerged as consistent barriers to teaching engineering across different types of schools and locations. Many teachers are interested in incorporating more engineering experiences. However, time, focus on standards & testing, and lack of administrative support are significant considerations for engineering education innovators and researchers to take into account when developing curricula. These findings also suggest that teachers would benefit from more training at both the pre-service and in-service levels in effective methods for teaching engineering, especially within an integrated unit that complements other core academic subjects. This paper discusses the results of the survey and its implications for disseminating successful engineering education initiatives that teachers feel empowered and prepared to teach.

Introduction

The next generation science standards (NGSS) call for all K-12 students to participate in engineering experiences, which will be a new subject area for many schools.[1,2] Teachers receive training in teaching science and math, but most elementary and middle school teachers have not received training in teaching engineering or technology. A National Association for Research and Teaching article provides an overview of engineering education to date, and the steps necessary for successful integration of engineering in the new NGSS. [2] They suggest a need for more training and new instructional resources to provide opportunities to engage students in STEM learning; however they caution that "effective, equitable, and accessible teaching and learning" require "careful planning and implementation".

There have been several nation-wide engineering curriculum program (Engineering is Elementary (EiE), Project Lead the Way (PLTW), Lego Engineering, etc.) as well as university-led initiatives in local schools[3,4,5] which have brought engineering to K-12 students. Engineering education innovators may anecdotally recognize barriers to widespread engineering curricula dissemination; however, a gap exists in the literature in understanding how teachers perceive incorporating engineering into elementary and middle school classrooms.

In a 2006 survey of 98 Arizona teachers, Yasar, et al. found that time and administrative support were barriers to teaching design, engineering, and technology (DET), and that all teachers were unfamiliar with DET and lacked the skills to teach it. [6] They also found differences among

subjects with different amounts of teaching experience and genders. Hsu, Purzer, and Cardella repeated this survey with 192 teachers from 18 states and found similar results.[7] Both authors suggested a need for more engineering training for both pre-service and in-service teachers.

Other research has looked at teachers' self-perceptions of their ability to teach engineering as a barrier to implementing engineering in K-12.[8,9,10,11] Yoon-Yoon, Evans, & Strobel developed the *Teaching Engineering Self-efficiacy Scale (TESS)* as a way to measure teacher needs and the effect of professional development. [10] In a review of P-12 engineering education initiatives, Brophy, Klein, Portsmore, &Rogers call for a "roadmap to show how educators, learning scientists, and engineers are currently bringing engineering concepts and practices to P-12 learners". [8] They go on to identify teachers' discomfort with teaching content they do not understand well as a significant problem for integrating engineering into elementary and middle school. They suggest an emphasis on training and partnerships between schools and universities.

As the push for incorporating more STEM into K-12 increases, it is important to understand teachers' attitudes about and experiences with engineering and STEM at the K-12 level. Previous research has utilized surveys to explore teachers' views [6,7]. However, these studies occurred before NGSS and much more understanding is necessary for successful engineering curriculum implementation.

This paper describes a recent survey that asked elementary and middle school teachers about their experiences with and opinions about teaching STEM and engineering. The results and their implications for engineering education initiatives will be discussed.

Research Questions

This survey was conducted as part of dissemination efforts for a new curriculum project; therefore it was intended as a tool to get a snapshot of American teachers' opinions about STEM. Specifically, we were interested in teachers' experience, understanding of age appropriate engineering curricula, and perceived barriers to teaching engineering in elementary and middle school. Did location, experience, and type of school affect these responses? We also asked questions about teachers' social media and curriculum planning habits, but these results are not discussed in this paper.

Method

The online survey was created in Qualtrics with qualitative multiple choice, likert scale, and open-ended questions. Participants were first asked about their background, location and experience before likert-type and open-ended questions about opinions and beliefs. We used STEM in the initial recruitment and questions because it is a buzzword in K-12 education and it was believed to be more familiar than engineering.

Most questions were required to progress. Participants were recruited through e-mail and social media. Consent was obtained at the beginning of the survey, and participants were prompted to provide contact information for an Amazon gift card upon completion. The survey questions were generated from literature reviews and teacher interviews and were reviewed by the research team. All research protocols and instrumentation were reviewed and approved by the university's Institutional Review Board.

Analysis of the results included descriptive and inferential statistics as well as qualitative analysis of open-ended responses. Three of the open-ended questions were coded separately by three researchers and then compared. Any disagreements were discussed until consensus was found.

Participants

The survey received 70 responses (9 were disqualified from analysis for not being 1st-7th grade teachers) from 15 US states (See figure 1). 54 (88%) self-reported as female, 49 (80%) were full-time in-classroom teachers, the majority (72%) had 10 years or less teaching experience, and most were early elementary teachers, though some taught multiple grades (figure 2). Full sample demographics are shown in table 1. Fourteen (24%) of respondents claimed prior experience teaching engineering (figure 3). Of these, only one had participated in Engineering is Elementary (EIE), though three had heard of it. Only one subject had heard of Project Lead the Way (PLTW), and none had participated. Unless otherwise stated, n=61 for all figures.

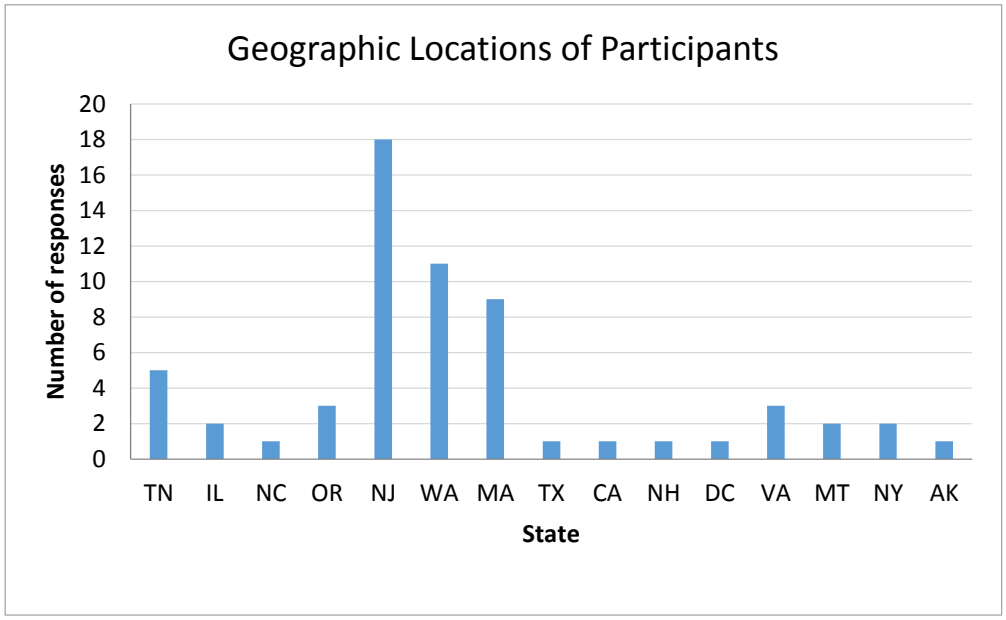

Figure 1: Participants Locations by State

Table 1: Participant Demographics

Gender	
Female	54
Male	7
Experience	
0-3	18
5-10	15
10-15	6
15+	11
School Type	
Public	47
Private	11
Charter	3
Teaching Role	
In-class teacher	49
Support teacher	7
Specialist	5
Type of class	
Contained	33
Rotating/Team	8
Subject specific	16
Other	4

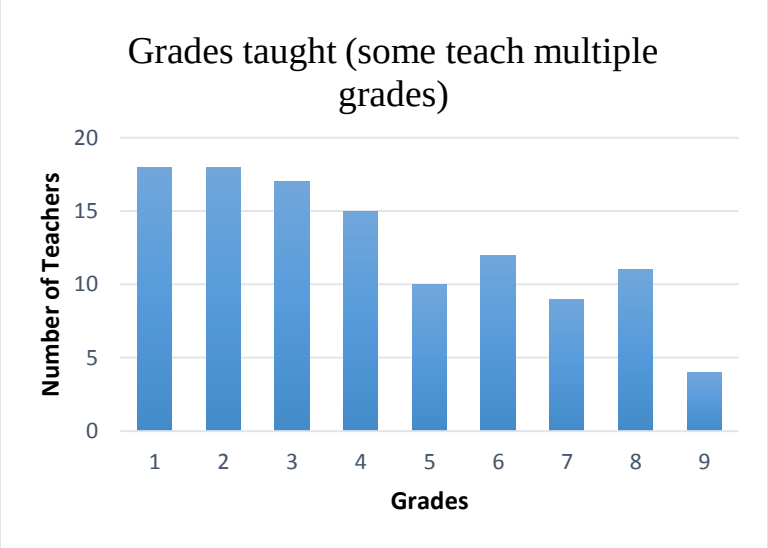

Figure 2: Grades Taught

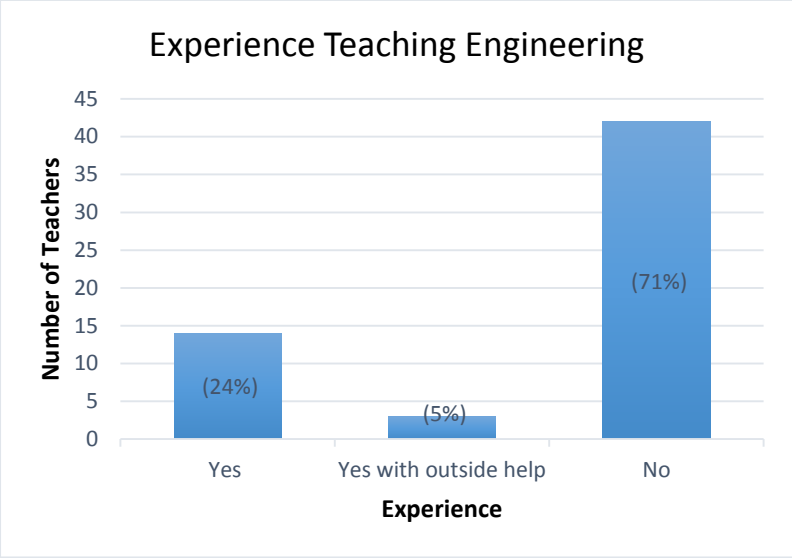

Figure 3: Engineering Experience

Results and Discussion

Opinions on STEM

The analysis focused on understanding teachers' opinions on and perceived barriers to teaching STEM. The means of the likert-type questions regarding STEM are shown in figure 4 where 3 is agree, 2 is neutral, and 1 is do not agree. The results show teachers are interested in STEM and would like to teach it, but feel they lack time and training which agrees with previous studies.[2,3,4] 33 (54%) did not feel confident in their ability to teach engineering, and 41 (67%) disagreed that they had learned effective methods for teaching STEM in their pre-service training. Of the 9 who agreed that they had learned effective teaching methods for STEM, 7 had less than 5 years of experience. Interestingly, only 16 (26%) disagreed with the statement "my administration/district puts emphasis on STEM". This may contradict previous studies which found administration support to be a major barrier for engineering and STEM. It is necessary to learn more what the impact of a neutral administration has on STEM implementation vs. an encouraging administration in future studies.

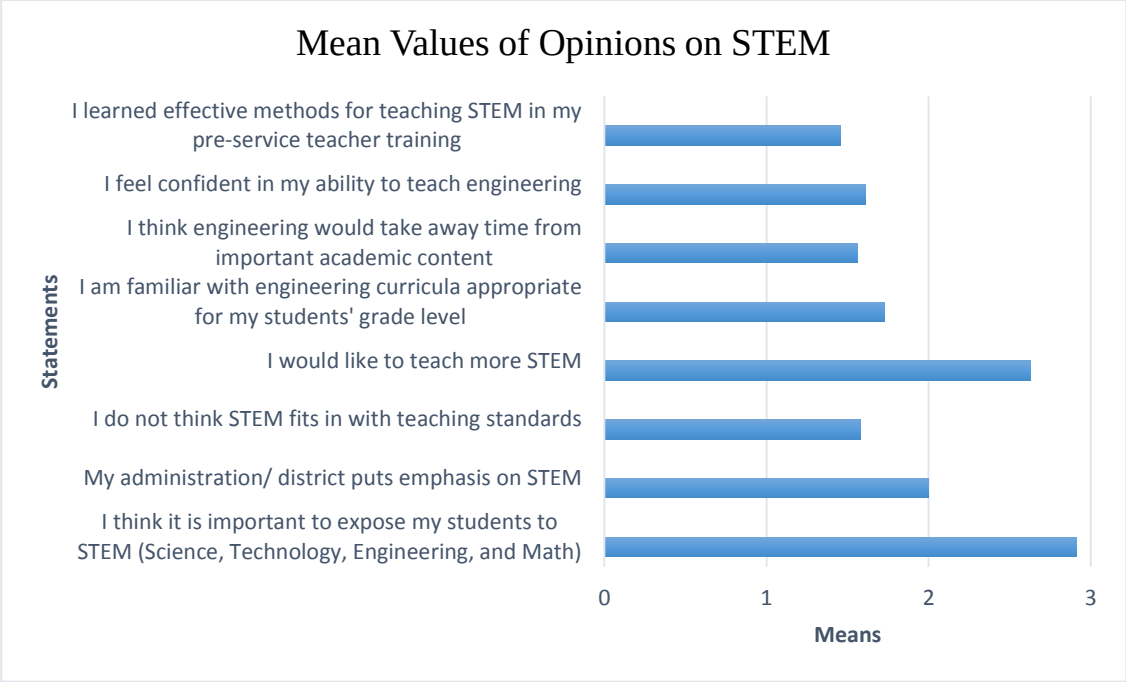

Figure 4: Mean Values of Opinions on STEM

A Mann-Whitney test was conducted to observe if any differences were present between the distribution of responses of teachers related to private and public schools with respect to the statement: "I do not think STEM fits in with teaching standards". "Private Independent" and "Private religious" labels were grouped in the category "Private". The independent samples Mann-Whitney test at a significance level of 0.05 did not reveal any significant differences between participants from private (*Mean*=2,36, SD=0.809) and public schools (*Mean*=2.4, SD=0.687) U=193.42, p=0.98 (figure 5).

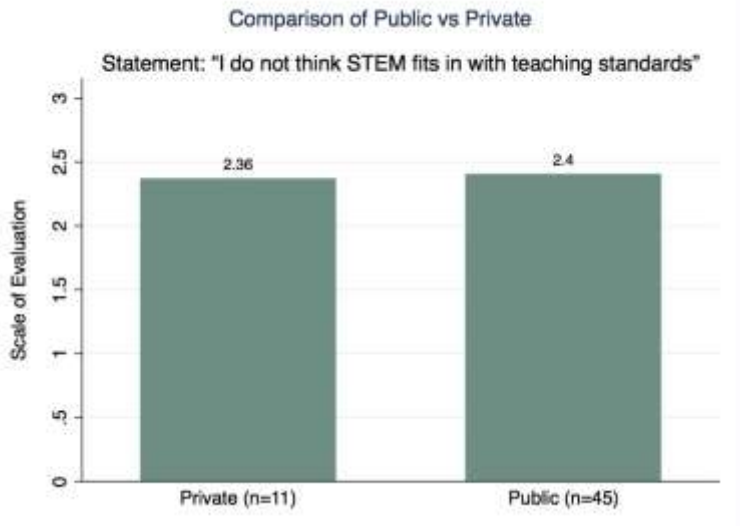

Figure 5: Public vs. Private School Opinions on STEM

A Mann-Whitney test was conducted to determine if significant differences were present with respect to the level of teaching experience at a significance level of 0.05. The test did not reveal any significant differences when comparing category A: 1 to 5 years of experience (*Mean*= 2.46,SD=0.74) with category B: more than 6 years of experience (*Mean*= 2.09,SD=0.83) , *U*= 196.5, *p*=0.1420 (figure 6).

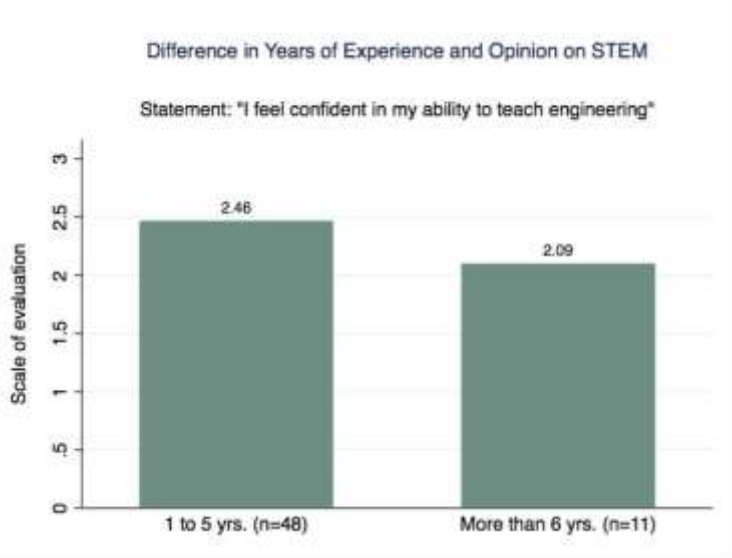

Figure 6: Difference in Years of Experience and Opinion on STEM

Barriers to Teaching Engineering

Participants were asked to choose barriers to teaching engineering in elementary and middle school. These responses are shown in figure 7. Time, support, and lack of training again emerged as themes to preventing engineering in the classroom, while student interest only had one vote. Surprisingly, materials/resources was ranked second and tied with time. This suggests that engineering curricula should use readily available materials that are already found in classrooms. The open-ended responses revealed a need for more "hands" in the classroom, but more research is needed to better understand the resources teachers need. Here again administrative support was considered less of a barrier than expected.

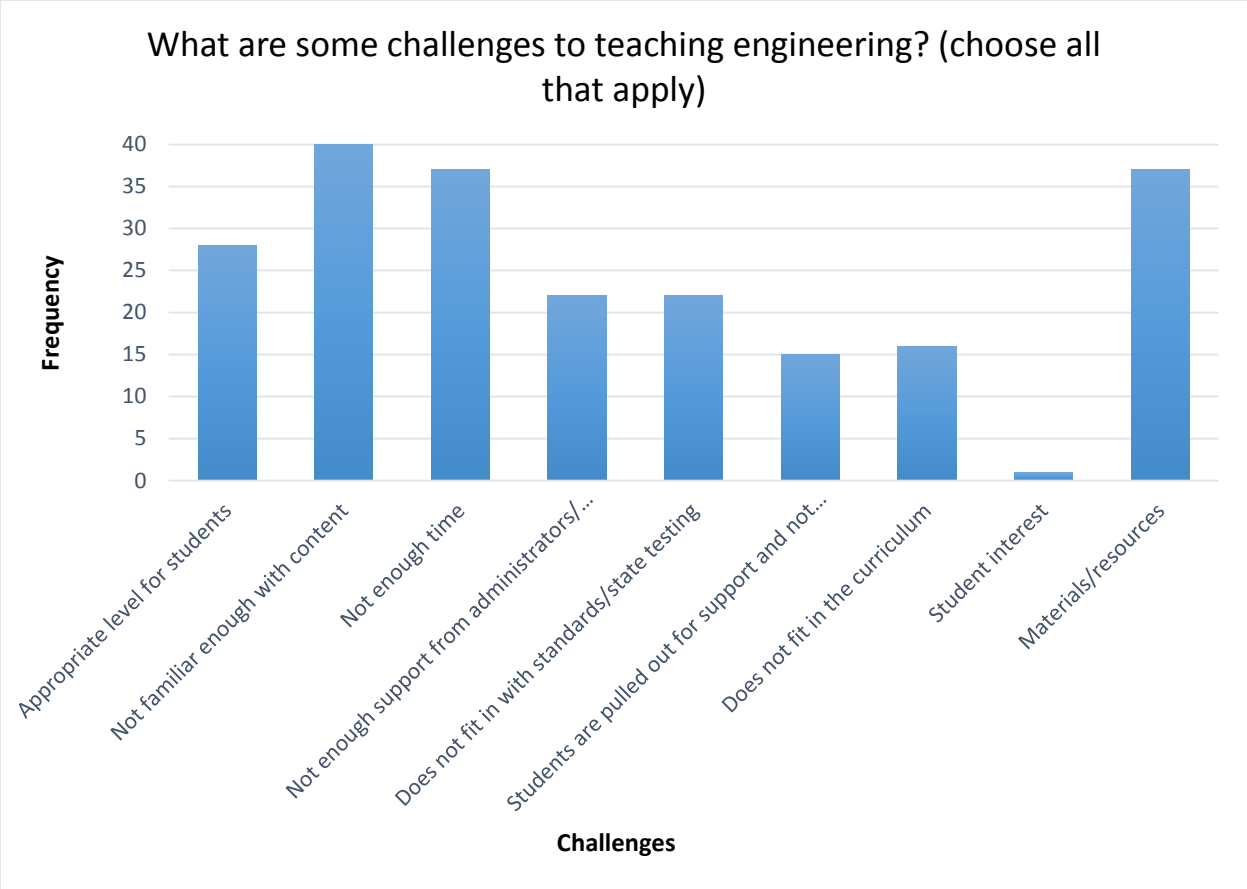

Figure 7: Challenges to Teaching Engineering

Influences

Participants were asked to rate how influences impacted their curriculum planning. The means are shown in figure 8 where 3 is agree, 2 is neutral, and 1 is do not agree. Time, meeting standards, in-classroom resources, and special needs were rated highest. These again agree with the general themes of time and testing as well as a need for resources. It is possible that teachers perceive juggling hands-on projects in a differentiated classroom as too difficult without support, but more research is needed into this area.

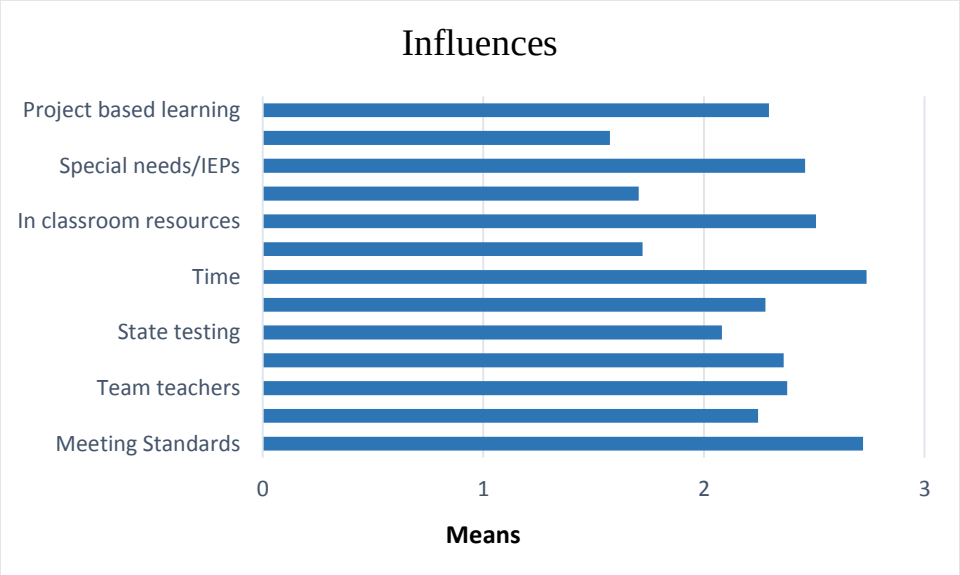

Figure 8: Influences on Curriculum Planning

Open-ended responses

We analyzed and coded open-ended responses to the question "In your opinion, what are some of the core elements of engineering? What is important for elementary and middle school students to learn about engineering?" All but two who claimed engineering experience mentioned core elements of engineering such as problem solving, prioritizing constraints, evaluating materials, and team work. Teachers who responded that they had had outside help planning engineering activities were able to identify some elements of engineering but were mostly concerned with understanding careers and "how stuff works". Those who claimed no experience with engineering had mixed success correctly identifying engineering and were more focused on using it to teach other core subjects such as math, reading, and science. Interestingly, three who claimed they did not know about engineering identified the core elements that we would call critical engineering skills. Shown in figure 10, the majority of participants identified core engineering skills, while 18 participants did not know or did not answer.

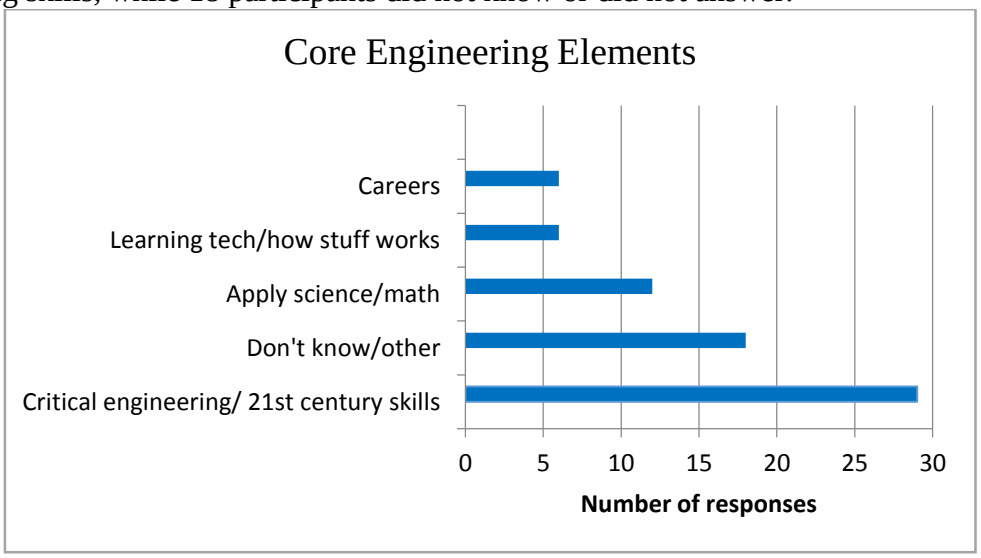

Figure 9: Coded Responses for Core Engineering Elements

Twenty-four participants provided a response to the question "Please describe some of the engineering activities you have done", though five indicated they had not done any. The coded responses for the other 19 are shown in figure 11. Eleven of these mentioned activities we would define as engineering with some aspect of designing, building, and testing. Four mentioned an outside curriculum such as engineering is elementary, and three mentioned an activity that used science and/or math but did not incorporate engineering.

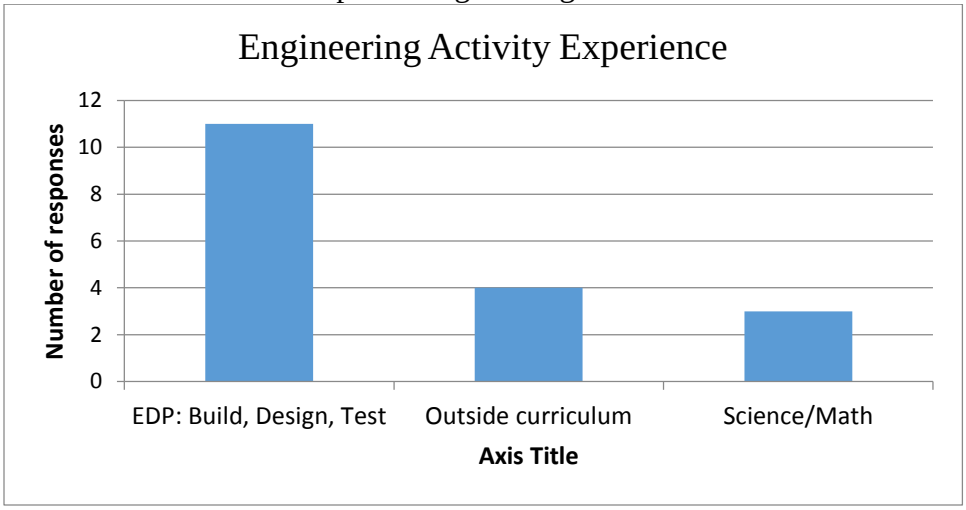

Figure 10: Coded Previous Engineering Experience

We also analyzed and coded responses to the prompt "Please share any thoughts you have about teaching engineering in elementary and middle school" which was the final non-demographic question. The 39 responses were coded for general themes as well as valence. The theme codes are shown in figure 12. Lack of appropriate training and knowledge again emerged as an important barrier to implementing engineering, as well as a lack of time for teaching in an already busy curriculum. Consistent with time was the need for more STEM integration; many participants mentioned using engineering to teach math/science in a way that was more engaging and allowed more time to include new subjects. The other category mostly includes positive comments about (90%) STEM/engineering that could not fall into the other theme categories. A few participants expressed they wished that they could incorporate more of the arts into their curriculum as well.

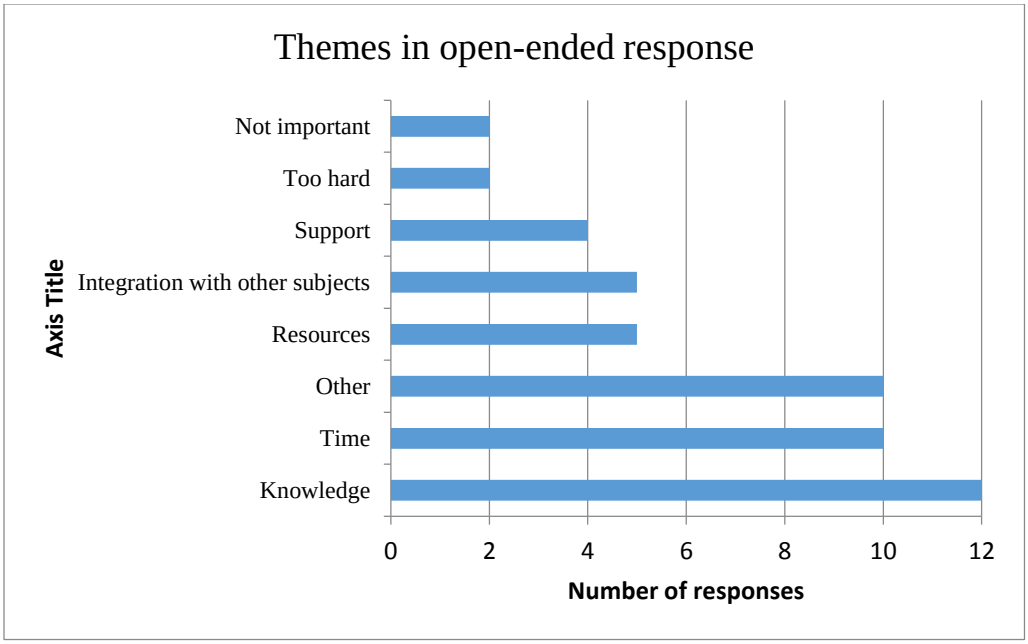

Figure 11: Coded Themes from final open-ended question on thoughts about teaching engineering in elementary and middle school

The open-ended responses were most interesting to us as a snapshot of teachers' opinions and beliefs, and some demonstrable full quotes are included below.

From a 4th grade teacher in Rural Montana:

> "Honestly, I have no idea. Number sense and comfort with math? Spatial elements? Willingness to think outside of the box and consider all factors? I would think it would be beneficial for elementary kids to know what engineering is and see engineers in action. Although, honestly, it would be great to see every job in action and I fail to see why this one (and all its extensions) is more necessary, other than it keeps us from falling behind China. So I suppose in the interest of national defense and all...."

This idea of career readiness was present in several responses and is an important element of both the Common Core State Standards (CCSS) and NGSS.[1,12] The link to future careers is an important aspect of engineering outreach initiatives to emphasize to teachers and administrators to improve adoption and retention rates.

From a private middle school science teacher in Urban Massachusetts:

> "I am a little frustrated by the way STEM has taken over science. I have never taken an engineering class in my life and I am resentful that the field of science has evaporated. I am also puzzled by how much math doesn't come into the conversation. Elements of engineering: design, test, modify, materials choice. Important things to learn: perseverance, cause and effect, how to help humanity"

This particular teacher had over 20 years of experience as a science teacher and provided interesting insight into one major barrier to including engineering: it is impossible to add engineering without taking away time from something else. This suggests that integrating engineering into other subject areas is key for increasing engineering in K-12. She suggests this in a general follow-up response question as well:

> "I really wish that there were a way to teach engineering as a separate course. I think that science has been asked to take on a lot of content that detracts from our primary focus. The full integration of STEM is an interesting model, but I am not convinced that it's going to serve all kids well. Maybe the current science curriculum is not either, but I feel more effective teaching science than teaching engineering."

The theme of interdisciplinary integration was echoed by several teachers. From a middle school math teacher in Suburban Washington:

> "Teaching engineering is the closest I've come to interdisciplinary study. Generally students study a social issue, like the world water crisis. They learn about it from the social studies viewpoint (poverty, economies, governments) and they write a paper for Language Arts and Science addressing the issue that they think is most important. In the lab, they are making observations, measuring outcomes, and keeping careful records. They are collaborative and communicative and fully engaged. In the coming year, we will follow a similar cross-disciplinary path with alternative energy. I know in advance that it will capture the energy of almost all of our students."

A 1st, 2nd, and 7th grade science teacher in Urban Massachusetts expressed similar sentiments:

> "I feel that it is essential, but schools need to reevaluate how it is done, and provide teachers with the time to do it. The teachers also need professional development in how to integrate other subjects with science, and less emphasis on math by itself and more on math as part of STEM."

Conclusions, Limitations, and Recommendations

This survey provided a snapshot of American elementary and middle school teachers across 15 states. Teachers are interested in teaching more engineering in an integrated model. Time, training, and support were consistent themes for the barriers to implementing engineering curricula, and they are important considerations for engineering education innovators to take into account when planning outreach and new curricula. This agrees with previous research, though we did not find statistically significant differences in different groups of teachers.[2,6]

Limitations

This study only included 61 participants from 15 states and thus cannot provide the full picture of American teachers' opinions and experience. A major limitation was that the survey was launched over the summer when the researchers hoped teachers would be less busy, but unfortunately, many teachers do not check their work email during the summer. As such, it was necessary to use personal networks and social networking sites to recruit participants which may account for the majority being younger teachers and congregated in certain states. There were too few male participants to study gender differences, so future studies should more actively recruit male participants.

Recommendations

This study provided a start to better understanding teacher perceptions, but more investigation is needed. A follow-up study should include more teachers and seek to have private and public schools represented from across all 50 states. Future surveys should ask specific questions about pre-service engineering training (participants from WA and NJ indicated significant pre-service experience) and more detailed questions about the resources needed to implement engineering in elementary and middle school. A follow-on study of administrators' opinions about engineering and STEM could also provide valuable insight into the challenges engineering education initiatives will face.

This study revealed a need for engineering education training. We suggest that more engineering methods be implemented at the pre-service level to empower newer teachers to feel confident in teaching engineering as required by NGSS. It is important to note that few participants knew of larger engineering curricular programs, so though this is a limited sample of teachers, more research is needed to understand the proliferation and dissemination of information about available curricula. Perhaps teachers would have a different perception of the possibility of teaching engineering in K-8 if they learned about the availability of these curricula in their pre-service training. [13] Additionally, future work should target teachers with experience teaching engineering to better understand what strategies worked to help empower them to teach engineering.

We suggest that engineering education innovators work within the time constraints of the modern school classroom to provide solutions that are easily implementable and support other important subjects. Integrating engineering into other subjects such as science or literacy could improve adoption and retention rates of engineering curricula.[14] Our Novel Engineering project seeks to provide an easy entry point to teaching engineering by using classroom literature as a context for engineering problems and found materials to build solutions. [13,15]

Bibliography

1) Achieve. (2013). Next Generation Science Standards. Retrieved from http://www.nextgenscience.org/next-generation-science-standards
2) Purzer, S., Moore, T., Baker, D., & Berland, L. (2014). *Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Engineering.* Retrieved from https://narst.org/ngsspapers/engineering.cfm.
3) Robelen, E. W. (2013). Elementary students tackling windmills. Education Week, 32(26), 19.
4) Lehman, J. D., Kim, W., & Harris, C. (2014). Collaborations in a community of practice working to integrate engineering design in elementary science education. Journal of STEM Education : Innovations and Research, 15(3), 21.
5) Hynes, M. & Swenson, J. (2013). The Humanistic Side of Engineering: Considering Social Science and Humanities Dimensions of Engineering in Education and Research. *Journal of Pre-College Engineering Education Research* 3(2), 31–42.
6) Yaşar, Ş, Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a Survey to Assess K-12 Teachers' Perceptions of Engineers and Familiarity with Teaching Design, Engineering, and Technology. *Journal of Engineering Education*, 205-216.

7) Hsu, M., Purzer, S., & Cardella, M. (2011). Elementary Teachers' Views about Teaching Design, Engineering, and Technology. Journal of Pre-College Engineering Education Research (J-PEER), 1(12), 31-39.
8) Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing Engineering Education in P-12 Classrooms. *Journal of Engineering Education*, 369-387.
9) Molitor, S.C., Kaderavek, J.N., Dao, H., Liber, N.J., Rotshtein, R., Milewski, G., & Czerniak, C.M. (2014). Engineering Teaching Behaviors in PK-3 classrooms. *Proceedings of the ASEE Annual Conference and Exposition*, June 2014, Indianapolis, IN.
10) Yoon Yoon, S., Evans, M.G., & Strobel, J. (2012). Development of the Teaching Engineering Self-Efficacy Scale (TESS) For K-12 Teachers. *Proceedings of the ASEE Annual Conference and Exposition*, June 2012, San Antonio, TX.
11) Wang, H.-H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: The impact of professional development on teacher perception and practice. *Journal of Pre-College Engineering Education Research, 1*(2), 1-13.
12) National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010) Common Core State Standards. Retrieved from http://www.corestandards.org/.
13) Wendell, Kristen Bethke (2014) "Design Practices of Preservice Elementary Teachers in an Integrated Engineering and Literature Experience," *Journal of Pre-College Engineering Education Research (J-PEER)*: Vol. 4: Iss. 2, Article 4.
14) Tafur, M., Douglas, K. A., & Diefes-Dux, H. A. (2014). Changes in Elementary Students' Engineering Knowledge Over Two Years of Integrated Science Instruction (Research to Practice). Presented at the American Society for Engineering Education Annual Conference and Exposition, Indianapolis, IN.
15) McCormick, M. (2014). Engineering for Colonial Times. Proceedings from Annual American Society of Engineering Education Conference and Exhibition, Indianapolis, IN.