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Ascertaining the Impact of P–12 Engineering Education Initiatives: Student Impact through Teacher Impact

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Abstract

The widespread need to address both science, technology, engineering, and math (STEM) education and STEM workforce development is persistent. Underscored by the Next Generation Science Standards, demand is high for P–12 engineering-centered curricula. *TeachEngineering* is a free, standards-aligned NSF-funded digital library of more than 1,500 hands-on, design-rich K–12 engineering lessons and activities. Beyond anonymous site-user counts, the impact of the *TeachEngineering* collection and outreach initiatives on the education of children and their teachers was previously unknown. Thus, the project team wrestled with the question of how to meaningfully ascertain classroom impacts of the digital engineering education library and—more broadly—how to ascertain the impacts of teacher-focused P–12 engineering education initiatives. In this paper, the authors approach the classroom impact question through probing self-reported differentials in: (1) teachers' confidence in teaching engineering concepts, and (2) changes in their teaching practices as a result of exposure to (and experiences with) K–12 engineering education resources and outreach opportunities. In 2016, four quantitative and qualitative surveys were implemented to probe the impact of the *TeachEngineering* digital library and outreach on four populations of K–12 teachers' confidence and practices, including the frequency with which they integrate engineering into their pre-college classrooms. Survey results document the teacher experience and perception of using hands-on K–12 engineering curricular materials in the classroom and help create a data-driven understanding of where to best invest future resources. The results suggest that the *TeachEngineering* curricular resources and outreach initiatives help teachers build confidence in their use of engineering curriculum and pedagogy in K–12 classrooms, impact their teaching practices, and increase their likelihood of teaching engineering in the classroom in the future.

Keywords: confidence, teacher, outreach, impact, pedagogy, pre-college, engineering education

Introduction

The Need

The connection between a technically literate workforce and the nation's global economic competitiveness, national security, and standard of living is well established (Institute of Medicine, 2007; Institute of Medicine, 2010; National Academy of Engineering, 2004; National Academy of Engineering, 2005; National Academy of Engineering, 2009), as is the integral role that science, technology, engineering, and math (STEM) education expansion and advancement plays in that marriage (Institute of Medicine, 2007; Institute of Medicine, 2010). National leaders have repeatedly called for improved K–12 STEM education (Institute of Medicine, 2007; Institute of Medicine, 2010), including the widespread adoption of design-based engineering education (National Academy of Engineering, 2005; National Academy of

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Engineering, 2009), the release of the engineering-infused national science standards (Next Generation Science Standards, n.d.), and efforts to improve the public perception and understanding of engineering (National Academy of Engineering, 2005; National Academy of Engineering, 2008).

TeachEngineering *Digital Library*

TeachEngineering (teachengineering.org) is an NSF-funded, free digital collection of more than 1,500 (and growing) original, hands-on K–12 engineering lessons and activities from 50 contributing programs, including contributions from 17 NSF GK–12 programs and 19 NSF Research Experience for Teachers (RET) programs. The *TeachEngineering* curricula are aligned with academic standards for state, national, and/or international science, mathematics, and technology, and use engineering (increasingly focused on engineering design) as the vehicle to integrate science and mathematics concepts for K–12 students. The collection was accessed by more than 3.2 million unique users in 2016, realizing an annual growth of 19%. Curriculum submitted for publication in the collection must be previously classroom tested, and is externally reviewed by at least one teacher and one engineer as part of the publication's quality assurance process.

TeachEngineering also provides professional development opportunities to teachers. In summer 2016, the project team conducted ten seminars for RET programs (reaching 106 teachers) through interactive Google Hangout webinars aimed at introducing teachers to engineering curricular resources and preparing them for—and ultimately guiding them through—the submission-to-publication process for their own classroom-tested engineering curricula.

Since its launch, *TeachEngineering* has been a multi-university collaboration (TeachEngineering History, n.d.). At present, the project is based at the University of Colorado Boulder with collaboration from Oregon State University. The University of Colorado Boulder is also home to a customizable, design-based engineering program, *Engineering Plus*, that (among dozens of other possibilities) facilitates concurrent secondary math or science teacher-licensure preparation through *CU Teach Engineering*, an engineering-degree based branch of the university's UTeach program. In its early education course in-class practicums, undergraduate engineering students in *CU Teach Engineering* use curriculum from the *TeachEngineering* digital library. Then, as they matriculate through the secondary math or science teacher licensure program, they begin preparing their own curriculum for the *TeachEngineering* collection and are guided through the submission-to-publication process by *TeachEngineering* editors.

For more than 10 years, the team at the University of Colorado Boulder has regularly held *Integrating Engineering into Your STEM Curriculum* professional development workshops, during which hands-on activities from the *TeachEngineering* collection were modeled. Dozens of local STEM teachers attended the workshops and then continued on to become "engineering mentor teachers," hosting (and mentoring) GK–12 fellows and all university UTeach students as they complete the engineering lesson practicum requirement during their first education courses.

To summarize, beyond the broad dissemination of K–12 engineering curricula facilitated by the *TeachEngineering* site, the project team has participated in (and continues to conduct) various engineering education outreach initiatives.

Impact

Though the *TeachEngineering* project team has always been data driven and engaged in project research (Sullivan et al., 2005; Reitsma, Klenk, Zarske, & Sullivan, 2010; Samson, Sullivan, Reitsma, & Soltys, 2015), the team has also long side-stepped a deep dive into the vast, lurking "impact" question; that is, how to meaningfully ascertain classroom impacts of the collection and, more broadly, how to ascertain the impacts of analogous teacher-focused P–12 engineering education initiatives. And, for good reason; when dealing with humans, capturing impact—"a marked effect or influence" (Oxford English Dictionary, n.d.)—is an incredibly tall order. After all, human impact has an inherent inner experience component, which is invisible, sometimes private, and often impossible to describe with words. Following a trip to the beach, for example, imagine you are asked, *how was it?* You might rely on various qualitative sensory descriptions ("breezy," "hot," "beautiful"), feeling descriptions ("relaxing," "enjoyable"), or quantitative descriptions ("-1.1 low tide bottomed out at 4:53 p.m.," "70℉, 68% humidity"). However, even as a poetic, data-equipped person, you would almost certainly be unable to fully communicate your inner experience of being at the beach and the impact that it had on you.

For *TeachEngineering*, like many other education initiatives, capturing the project's comprehensive impact hinges upon knitting together the pieces of individual (personal) impact, which themselves are nebulous and won't "hold a stitch." In the people-centered engineering education research arena, this is a considerable challenge facing researchers, and one that must be reconciled, often on a study-by-study basis.

Individual Impact to Broad Impact

Since 1997, NSF proposals have been evaluated in terms of intellectual merit and "broader impacts of the activities they propose to undertake." The NSF Director is required to "issue a report to Congress on the effect of the 'Broader Impacts' Criterion (BIC) on the types of activities funded by NSF" (Holbrook & Frodeman, 2007).

Attention to broad impact "tends to occur when a proposal is being reviewed, rather than when the work is complete and is being reported" and broad impact is "poorly articulated in some funded NSF proposals" (Nadkarni & Stasch, 2013). As NSF reports, "experience shows that while most proposers have little difficulty responding to the criterion relating to intellectual merit, many proposers have difficulty understanding how to frame the broader impacts of the activities they propose to undertake" (National Science Foundation, n.d.). NSF provides five prompting questions for consideration to probe impact, paraphrased as pertaining to: (1) advancing discovery and understanding while promoting teaching, training, and learning, (2) broadening the participation of underrepresented groups, (3) enhancing the infrastructure for research and education, (4) enhancing scientific and technological understanding, and (5) benefitting society (National Science Foundation, n.d.).

Engineering education researchers have long grappled with impact questions (in the ASEE conference archives alone, "impact" is mentioned in 568 titles, with "measuring impact" in 24), and proposed various study-specific methods to probe impact. In one study, for example, student impact of project-based service learning (PBSL) was described through engineering college retention, participation by underrepresented students, fulfillment of ABET learning outcomes, and enhanced student preparation to practice engineering design (Bielefeldt, Paterson, & Swan, 2009). Another study that focused on measuring the impact of infusing entrepreneurship across engineering curriculum used measures of self-efficacy and locus of control (Borchers, Park, Harris, Riffe, & Tavakoli, 2010). Student attitudes toward math and science were used to measure the impact of an elementary school engineering outreach program (Lundstrom & Moskal, 2012). More related to the teacher-focused *TeachEngineering* project, a study measuring the impact of a K–12 teacher internship program, used pre- and post-surveys that asked teachers about the engineering design process, 21st century skills, collaboration, and project-based learning; impact was reported as differentials between the pre- and post-surveys (Bowen, 2013).

TeachEngineering *Impact*

Compounding the enigmatic task of capturing personal impact is *TeachEngineering*'s anonymous user base. As thousands of anonymous users access the online collection each day, implementing pre- and post-surveys for a representative, random sampling of users is not (at least yet) possible. Instead, the team started with a quick, one-time, self-reported means of ascertaining (1) who is using the site and (2) the site's impact on teachers.

Confidence is critical to teacher efficacy; even a neophyte instructor who does not yet feel confident must act confidently (Eison, 1990). Teacher confidence (both self-confidence and content-confidence) oozes over into other key elements of teaching efficacy, such as "1) organization, structure, or clarity, 2) teacher-student interaction or rapport, 3) teaching skill, communication, or lecturing ability, 4) workload or course difficulty, and 5) grading examinations" (Eison, 1990).

In this paper, the authors approach the classroom impact question by exploring self-reported differentials in: (1) teachers' confidence in teaching engineering concepts, and (2) changes in their teaching practices as a result of exposure to (and experiences with) K–12 engineering education resources and outreach opportunities.

Methods

Surveys

In 2016, four 10-minute quantitative and qualitative Qualtrics surveys were implemented to probe the impact of the *TeachEngineering* digital library and outreach on four populations of K–12 teachers' confidence and practices, including the frequency with which they integrated engineering into their classrooms (Table 1).

The surveys employed a combination of Likert-style, open-ended, and multiple-choice questions. The full *TeachEngineering* site pop-up survey is provided in Appendix A. The other three surveys covered the same content, but were modified to fit the context for each respective survey population.

Data Analysis

Though many researchers in the engineering education community treat Likert-style data as continuous (thereby reporting means and standard deviations), the authors take a more conservative statistical analysis approach and do not assume that level of data resolution. Instead, the data were

Table 1
Descriptions of the *TeachEngineering* (TE) impact surveys for four K–12 teacher populations.

Survey	Population
TE site pop-up survey	TeachEngineering.org users from September 27, 2016 to November 4, 2016 (n = **373,840**)
TE published author survey	**38** RET participant teachers whose curricula were published in the collection between January 1, 2014 and September 19, 2016
TE RET outreach survey	**106** RET participants who attended a TE Google Hangout professional development webinar in summer 2016
TE partner teacher survey	**64** K–12 engineering mentor teachers who attended a hands-on *Integrating Engineering into Your STEM Curriculum* professional development workshop at the University of Colorado Boulder

treated as independent and nominal; and thus descriptive statistics were used to report on survey responses. Comparisons in Likert responses between groups were conducted using chi-square tests, after dichotomously grouping the data (i.e., separating those that were "highly confident" or "confident" from those that were "somewhat confident," "not very confident," or "not at all confident"). Tests were performed in Microsoft Excel.

Results and Discussion

TeachEngineering *Site User Impact*

During the 39 days that the pop-up survey ran, the *TeachEngineering* site had 373,840 unique users; 386 elected to take the survey. This self-selected, proportionally tiny sampling cannot be considered representative of the population of site users as a whole, and the survey responses should not be extrapolated in that way. Rather, the results provide a rough-cut foray into learning about the people behind the screens, what they are doing with the *TeachEngineering* curricula, and how it is impacting them and their students (if they are, in fact, teaching in classrooms).

Just over half (51%) of the respondents indicated that they were K–12 teachers (almost one-quarter of whom had been teaching for at least 20 years), 6% indicated that they were "K–12 educator[s] in an informal learning setting," 3% "engineer[s] engaged in K–12 outreach," and 2% "community member[s] engaged in K–12 outreach." Another 38% of respondents identified with an "other" category, which included students, homeschool teachers, university faculty, and community college instructors, as well as a self-described curriculum developer, a science instructional coach, and a teacher's aide.

The users varied in how often they reported teaching *TeachEngineering* curriculum in a classroom, ranging from: "weekly" (20%), "monthly" (15%), "5–10 times a year" (11%), "2–4 times a year" (10%), "once a year" (6%), and "never" (38%). The authors were surprised by how many respondents browsing the collection (and volunteering for a survey) reported that they had "never" taught curriculum from the collection in a classroom, which prompts the question: *what were they doing on TeachEngineering?* Many of them also reported that it was their first time on the site, making it reasonable to guess that some hadn't yet had the opportunity to teach the curriculum in a classroom, but they might have had plans to do so in the future. Of those who had taught curriculum from the site in a classroom, 94% anticipated that they would continue doing so in the future.

Notable in terms of impact, more teachers were "highly confident" or "confident" in teaching engineering concepts to their students after using the *TeachEngineering* digital library curriculum (85%) as compared to before (35%) (chi-square $p < 0.001$) (see Table 2).

The vast majority of respondents "strongly" (73%) or "somewhat" (16%) agreed that "after using the *TeachEngineering* digital library, [they] are more likely to integrate engineering concepts into [their] teaching."

Many users shared student benefits they had observed from using *TeachEngineering* curricula. As demonstrated below, student engagement was commonly mentioned:

- "I am a physics teacher that has been looking for a more creative way to introduce vectors. My honors physics [students] are having a blast with the vector voyage activity!"
- "Students are engaged and thinking. That's a definite plus!"
- "My students are engaged in critical thinking, they have a lot to say about it and my principal is impressed."
- "My students have loved using this curriculum. They have been so engaged and excited. They meet me at the door asking what we're going to do in science today!"
- "Students are more engaged and excited about learning. Their conversations reflect what they are being taught."
- "High engagement, rigorous questioning, critical thinking."
- "Student growth can be observed throughout the year as students learn to work together cooperatively, plan effectively, and think creatively."
- "All of my students are actively engaged into [sic] the projects… They enjoy to the degree that I have no work habit or behavior problems."
- "[Students] learn to be more self-motivated."
- "The benefits that I see in my students are excitement about engineering, math, science, and arts. They want to

Table 2
Frequency counts of responses to two Likert-style survey questions that probed *TeachEngineering* (TE) site users' confidence in teaching engineering concepts.

Survey Question	Not at all confident	Not very confident	Somewhat confident	Confident	Highly confident
Before using the TE digital library content, how confident were you in teaching engineering concepts to your students? ($n = 233$)	20 (9%)	45 (19%)	87 (37%)	49 (21%)	32 (14%)
After using the TE digital library, how confident are you in teaching engineering concepts to your students? ($n = 229$)	6 (3%)	2 (1%)	27 (12%)	106 (46%)	88 (38%)

> come to school and learned [sic] about engineers. I see progress in mathematical strategies and problem solving."

As depicted by this sampler of respondent feedback, without the firsthand ability to ask students in the classrooms about their experiences with the *TeachEngineering* curricula, the authors found many teachers volunteering profuse, qualitative, and overwhelmingly positive anecdotes about how they perceived their students to be impacted by the curriculum.

TeachEngineering *Published Teacher-Author Impact*

Of the 46 RET teacher-authors invited, 23 (43%) responded to the published author survey. Each respondent had been teaching for at least three years; eight had 6–10 years of teaching experience, five had 11–20 years of experience, and four had been teaching for more than 20 years. The respondents taught a range of third- to twelfth-grade students. Sixteen said they had taught *TeachEngineering* curricula in their classrooms, but varied considerably in frequency ("5–10 times a year" = 4; "2–4 times a year" = 5; "once a year" = 6); those that had not taught the curriculum cited reasons ranging from "because I didn't know about this resource" to "I have very limited time with my students and it's hard to add new content." Three-quarters of the respondents anticipated that they would use *TeachEngineering* engineering curricula in a classroom in the future.

Some teachers found the submission-to-publication process "rigorous," "lengthy and detailed," and "very time consuming." On the other hand, one teacher said it was "very easy," "encouraging and supportive," "efficient," and "respectful of time," while another teacher said it was "difficult at first but got easier with experience." Several teachers noted satisfaction in their final published products ("at the beginning it is difficult, but it is rewarding to see the final product"; "the editing and feedback process made my lesson much stronger").

In response to being asked how they were personally impacted by the submission-to-publication process, several teachers again cited a sense of accomplishment, while others ranged in their responses: "[it] made me a better researcher and writer"; "[it] impacted me personally by giving me the confidence to submit more curriculum to *TeachEngineering* or to other publications. As well as, [sic] presenting my ideas to others"; "it helped [me] understand how to produce a quality activity"; "[it] makes me, a teacher, feel empowered and confident in implementing more engineering practices"; "it has been the best learning experience I have had to produce high-quality lessons that really impact students."

Also noteworthy in terms of impact, all but four teachers (80%) either "strongly" or "somewhat" agreed that "after going through the *TeachEngineering* submission-to-publication process, [they] are more likely to integrate engineering concepts into [their] teaching.

RET Outreach Impact

Following their *TeachEngineering* Google Hangout seminars, 44 RET participants (42%) responded to the survey. Almost two-thirds (61%) had at least 11 years of teaching experience, and all but five were secondary math and science teachers. Forty of the teachers (91%) had never heard of *TeachEngineering* before the webinar, while 42 (95%) anticipated that they would use curriculum from the site in their classrooms in the future—a high pay-off for a 60-minute time investment on the team's end.

TeachEngineering *Partner Teacher Impact*

Twenty-one *TeachEngineering* "engineering mentor teachers" (33% of the 64 invited) responded to the impact survey. Each respondent had taught for at least six years—13 had taught for 11 or more years—and were almost evenly split between elementary (8), middle (6), and high school (7), with one pre-K teacher. The teachers varied in how often they used *TeachEngineering* curriculum: "weekly" (1), "monthly" (5), "5–10 times a year" (1), "2–4 times a year" (8), "once a year" (3), and "never" (3).

As with the site user survey respondents, many more partner teachers were "highly confident" or "confident" in teaching engineering concepts to their K–12 students after using the *TeachEngineering* digital library curriculum (78%), as compared to before (42%) (chi-square $p = 0.027$) (see Table 3). Eighty-nine percent of teachers "strongly" (12)

Table 3
Frequency counts of responses to two Likert-style survey questions that probed *TeachEngineering* (TE) engineering mentor teachers' confidence in teaching engineering concepts.

Survey Question	Not at all confident	Not very confident	Somewhat confident	Confident	Highly confident
Before using the TE digital library content, how confident were you in teaching engineering concepts to your students?	1	5	5	7	1
After using the TE digital library, how confident are you in teaching engineering concepts to your students?	0	0	4	8	6

Note: Two survey respondents chose not to answer the first question; three skipped the second question.

or "somewhat" (4) agreed that "after using the *TeachEngineering* digital library, [they were] more likely to integrate engineering concepts into [their] teaching"; the remaining two teachers (three skipped the question) indicated that they "neither agree nor disagree." Eighteen teachers anticipated that they would use *TeachEngineering* curriculum in their classrooms in the future.

Some teachers reported that using the *TeachEngineering* digital library impacted their personal teaching philosophy or pedagogy, while others indicated that it served as more of a reinforcement: "[it has] improved my use of student talk time and collaboration"; "broadens the tool box for engaging students in problem-based learning"; "I am more apt to let my students create and build without too much direction. In a lot of cases they fail but it only makes them more determined to figure out a solution . . . before I would want everything they did to be guided and successful"; "it already goes along with what I believe about good teaching."

Summary and Conclusions

The results from this study suggest that both the *TeachEngineering* curricular resources and outreach training help teachers build confidence in their use of engineering in K–12 classrooms, impact their teaching practices, and increase their likelihood of teaching engineering in the classroom in the future. These findings indicate that continuing to invest project resources into adding new curricula to the digital library collection and expanding teacher outreach is money well spent.

User metrics tracking of the *TeachEngineering* collection reveals ongoing indicators of teacher usage. For example, site traffic patterns mirror the U.S. academic schedule, and print button clicks on the curriculum write-up pages indicate that a lot of printing is happening from the site.

The bulk of the curricular contents in the collection are the original and classroom-tested outcomes from multi-year National Science Foundation grantee programs at more than 40 U.S. university locations. These high-quality curricular gems, from individual faculty-teacher partnerships scattered around the country, are available to teachers nation- and world-wide. As such, the collection serves as a dissemination venue for NSF by publishing and widely disseminating curricula developed through NSF K–12 engineering education grants.

Working to understand classroom impact is tenuous. At its core, the *TeachEngineering* project is analogous to other teacher-focused P–12 engineering education initiatives. The authors hope that readers engaged in such projects find takeaways in the approach to probe classroom impact through exploring self-reported differentials in (1) teachers' confidence in teaching engineering concepts, and (2) changes in their teaching practices as a result of exposure to (and experiences with) K–12 engineering education curriculum, pedagogy, and outreach opportunities (i.e., how often they bring engineering concepts into the classroom).

Here you might ask, *how does this increased teacher confidence in teaching engineering concepts impact students*? This approach stops short of probing the impact for the ultimate student consumers. Though, while that question is not (yet) answered from our research, perhaps it is well answered on an intuitive level. Those readers who have spent many years as students themselves surely have an intuitive sense of the student-experienced difference between a teacher confident in his/her delivery and one who is unsure of him/herself. Teacher impact is a sustainable, year-to-year investment in student impact; teacher changes are seen—and felt—by students, and can have lasting (again, sometimes invisible, private, or nonverbalized) impact on individual students.

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Appendix A: *TeachEngineering* Site Pop-Up Survey

1. How often do you teach curriculum from the *TeachEngineering* digital library in a classroom?

   a. Weekly
   b. Monthly
   c. 5–10 times a year
   d. 2–4 times a year
   e. Once a year
   f. Never

2. Please tell us about any student benefits you see from using *TeachEngineering* curriculum.

3. Do you anticipate that you will continue to use *TeachEngineering* curriculum in your classroom?

   a. Yes
   b. No

4. Before using the *TeachEngineering* digital library, how confident were you in teaching engineering concepts to your students?

   a. Highly confident
   b. Confident
   c. Somewhat confident
   d. Not very confident
   e. Not at all confident

5. After using the *TeachEngineering* digital library, how confident are you in teaching engineering concepts to your students?

   a. Highly confident
   b. Confident
   c. Neutral
   d. Not very confident
   e. Not at all confident

6. Please rate your agreement with the following statement:
   After using the *TeachEngineering* digital library, I am more likely to integrate engineering concepts into my teaching.

   a. Strongly agree
   b. Somewhat agree
   c. Neither agree nor disagree
   d. Somewhat disagree
   e. Strongly disagree

7. What uses, value, benefits, and impact have you experienced using the *TeachEngineering* digital library?

8. How has using the *TeachEngineering* digital library impacted your personal teaching philosophy or pedagogy?

9. How has using the *TeachEngineering* digital library helped prepare your students for college and career?

10. Please tell us about yourself. I am a(n):

    a. K–12 teacher
    b. K–12 educator in an informal learning setting
    c. Community member engaged in K–12 outreach
    d. Engineer engaged in K–12 outreach
    e. Other (text box)

[For K–12 teachers]

11. For how many years have you been practicing as a teacher?

    a. 1–2 years
    b. 3–5 years
    c. 6–10 years
    d. 11–20 years
    e. 20+ years

12. Select all grade bands that you teach:

    a. Pre-K
    b. K–2
    c. 3–5
    d. 6–8
    e. 9–12
    f. Other

[For middle and high school teachers]

13. What subject areas do you teach? (Select all that apply)

    a. Biology
    b. Chemistry
    c. Math
    d. Physics
    e. Engineering
    f. STEM
    g. Other (text box)