Integrated Engineering in Elementary Education: Tackling Challenges to Rural Teacher Training

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Abstract

Researchers worked with a rural education cooperative to deliver engineering education professional development to 38 elementary teachers. Teachers received training in Engineering is Elementary (*EiE)* and *Family Engineering* curriculum and then implemented those lessons with their 2nd-5th grade students. Researchers administered pre- and post- measures to gauge changes in teachers' and students' knowledge and perceptions regarding engineering. Additionally, changes in teachers' self-efficacy of teaching engineering and students' attitudes about science and engineering were measured. This article discusses the value of elementary engineering education in rural communities.

Keywords: Engineering education; professional development; elementary; rural schools

Introduction

Science education in elementary (K-6) curriculum is often lacking and leads to widespread lack of preparation and misconceptions about fundamental science ideas in middle and high school students.[1] Researchers have documented that elementary classroom science instruction is typically limited and of low quality.[2,3,4,5] Further, results from a 2013 national survey indicated that elementary teachers perceive that they are not prepared to teach science.[6] Now, the integration of engineering practices within the Next Generation Science Standards (NGSS) require elementary teachers to have an understanding of engineering that goes beyond traditional science teaching.[7] Thus, elementary teachers will need professional development to introduce them to engineering processes and help them to teach these concepts within a context that is appropriate and engaging for elementary students.

Professional development is often described as a reform strategy for STEM education, however discussion about rural locales is nearly absent from the educational policy literature describing the role of teacher quality on student achievement.[8] Rural schools may struggle with integrating engineering education because rural schools, in general, have more limited access to quality STEM teachers and teaching resources. Furthermore, rural elementary school settings are typically geographically isolated from more readily available training opportunities in urban areas. Additionally, factors such as insufficient mentoring, lack of access to university resources, and problems differentiating instruction for underachieving students may influence STEM teacher retention in rural areas.[9]

Given the lack of success of informal STEM programming in rural areas (i.e. after-school and summer programs) due to transportation problems, one important function of STEM professional development might be to offer networking opportunities for STEM teachers in nearby rural school districts, as well as relevant experiential curricula for rural classrooms.[9,10] As such, the main objective of this research project, *Rural Readiness for Engineering Education (RREE),* was to meet the need for elementary teacher engineering education in rural Oklahoma by providing a comprehensive engineering education curriculum training workshop and

supplying shared resources for classroom implementation. The project aimed to increase teacher engineering education self-efficacy and thus student understanding about and interest in engineering processes and careers. In this paper, we focus on the value of the *RREE* project to provide professional development to rural schools and present preliminary findings from the study. Specifically, this paper addresses some preliminary research questions related to the potential impact of training workshops on the engineering knowledge of rural teachers and students: how did participating in the *RREE* professional development affect (a) teachers' and students' knowledge and perceptions regarding engineering, (b) teachers' self-efficacy of teaching engineering, and (c) students' attitudes about science and mathematics?

Related Literature

There is a nationwide emphasis on integrating engineering education into P-12 learning. The impetus in the U.S. stems from a projected need to increase the quantity and quality (and diversity) of future engineers.[11, 12] However, a number of barriers and challenges exist to the integration of engineering in traditional science classrooms. For example, Yasar and colleagues found that (a) K-12 teachers held stereotypical views of engineers, (b) elementary teachers placed less value on teaching engineering design than secondary teachers do, and (c) teachers, in general, lacked confidence in the abilities to teach engineering design activities.[13,14] Further, the limited available research indicates that elementary teachers report feeling unprepared to teach engineering practices.[15, 16] Below we explore these interrelated challenges to teacher professional development in engineering education, as well as some challenges uniquely faced by teachers in rural schools.

Misconceptions about engineers and engineering careers. Current literature indicates that many teachers, including elementary teachers, have stereotypical images of scientists and negative views towards science.[17,18] Similar problems plague engineering education, as many teachers and students do not understand what engineering is and often confuse the work of engineers with the work of scientists, construction workers, or mechanics.[19-22] Many elementary teachers may need help in recognizing and understanding the role of engineering in the world around them.[23]

Elementary STEM education and early-aged engineering career awareness are increasingly considered as important components to meeting the demand for pre-college preparedness and increased engineering workforce diversity.[24,25] However, recent reports indicated that teachers are not doing an adequate job of teaching students about potential STEM careers. [26] Many students who are capable of becoming engineers do not because they do not understand what engineers do or do not think they have the abilities needed to become an engineer.[27] These findings are particularly common for underrepresented groups such as females and minorities.[25] Further, elementary teachers often do not view engineering as an appropriate career choice for all students believing that only smart teachers and students can learn engineering concepts.[28,29]

Challenges to integrating engineering in elementary science. To date, there has been limited research on elementary teacher professional development in engineering content and design processes.[30] While many nationally developed standards for science and technology

include engineering standards for elementary learners, there remains the need for teacher professional development which provides a roadmap for educators to define and implement engineering concepts and processes.[28] For example, the NGSS embed engineering practices throughout the grade-level learning progressions, but the NGSS Framework may misrepresent the uniqueness of engineering practices (e.g. design process and applications to problem solving) by conflating them with science practices.[7, 31]

Even when teachers perceived the incorporation of engineering activities as potentially enhancing their science learning goals, there remains the challenge of teacher familiarity, preparation, and eventual fluency in engineering education. While some large-scale research exists on the effectiveness of teacher professional development using the *Engineering is Elementary (EiE)* curriculum, there are many questions remaining about how to prepare teachers for implementing engineering education.[16] Cunningham's and Carlsen's call for professional development outlines five guiding principles for achieving effective teacher preparation: "engage teachers in engineering practices, model pedagogies that support those practices, give teachers experience as both learners and teachers, develop teachers understanding of the fundamentals of and interactions between science and engineering, and help teachers to understand engineering as a social practice" (p. 204).[31]

Teacher Fluency and Self-Efficacy. There is limited research to suggest a link between elementary teachers' personal understanding of engineering and their motivation to engage in engineering education.[32] As such, we need a better understanding of the affective issues of teaching engineering in the elementary settings. Teaching self-efficacy theorizes that self-efficacy influences teacher level of classroom engagement and teaching self-efficacy scales focus on teaching and learning outcomes associated with specific context.[33-36] Research findings indicate that teaching self-efficacy is content specific and many measures exists to measure content-specific teaching self-efficacy including the Science Teaching Efficacy Beliefs Instrument and the Mathematics Teaching Efficacy Beliefs Instrument.[37,38] Then Yoon, Evans, and Strobel developed the Teaching Engineering Self-Efficacy Scale (TESS) which is the first validated measure of K-12 engineering teaching efficacy.[39] While teacher self-efficacy is a relatively stable construct, with the opportunity for teachers to participate in engineering activities can help them develop their confidence and increase their teaching efficacy related to teaching engineering concepts.

STEM professional development in rural contexts. There are challenges to STEM reform, in general, and integrating engineering education, specifically, in rural areas. Rural schools are often geographically isolated and lack funding and sufficient resources, thus rural students are limited in the STEM courses and programs available to them.[40, 41] Rural communities might also lack engineer role models for these underrepresented students. Oftentimes, students' knowledge of potential STEM careers is limited to those they commonly see in their local communities: mechanic, veterinarian, physician.[42, 43] These factors, combined with a lack of access and exposure to STEM learning experiences, imply that rural students are unlikely to pursue engineering without some form of intervention.[41]

Rural teachers often do not have the same opportunities for professional development when compared with urban and suburban teachers. Additionally, rural schools often struggle to

recruit and retain quality science and mathematics teachers. Teacher shortages, in turn, affect STEM education because teachers specializing in other fields are required to teach STEM subjects for which they are unprepared to teach. [9] A review of literature on rural schools reveals the need for research about (a) effective strategies for building teacher content knowledge and pedagogical skills to achieve the greatest impact on student achievement and (b) alternative organizational structures, such as regional cooperatives, that minimize costs and maximize student achievement. [44, 45]

Context

Framed as an issue of social justice for rural communities, prior research in teacher professional development in Oklahoma indicates rural teachers face a high degree of professional, social, and cultural isolation, as well as a lack of access to STEM professional development.[46] More than two-thirds of school districts in Oklahoma are classified as rural.[47] These schools face several challenges including poverty, limited resources, and difficulty recruiting and training teachers.

In 1993, as an effort to address the problem of rural school resource allocation, Oklahoma legislators authorized the creation of Interlocal Cooperative Districts allowing boards of education in two or more school districts to jointly and comparatively perform regional educational services (H.B. 1393). These cooperatives are authorized to seek state and federal grants for member districts and often provide a broad range of educational services, including professional development and curriculum mapping and development. The *RREE* was funded through a state-level College, Career and Citizen Ready competitive grant program and involved collaboration with Oklahoma's most comprehensive regional educational cooperative that includes 15 school districts across seven rural counties, many with high Native American student populations.

The *RREE* project engaged 39 elementary teachers in elementary engineering education professional development workshop using the *Engineering is Elementary* (*EiE*) and the *Family Engineering* (http://www.familyengineering.org/) curricula. Complete information about the *EiE* program is outlined by Cunningham, including curricula goals and structures of the curriculum.[29] The program was designed with the intent to engage students from marginalized groups and to reinforce science concepts through application. In addition, the curriculum includes detailed teacher professional development materials for use during curriculum training workshops. The *Family Engineering* curriculum introduces elementary-aged children (and adults) to engineering concepts and careers through hands-on learning experiences in an informal setting. Both *EiE* and *Family Engineering* promote 21st Century skills of critical thinking, inquiry, creativity, teamwork, and collaborative problem solving (http://www.skills21.org/).

Participating 2nd-5th grade teachers attended one professional development session at the regional cooperative headquarters, either in August (n=20) or January (n=19). These one-day events included training on one *EiE* curriculum and the *Family Engineering* kit. The one-day workshop followed the prescribed *EiE* 6-hour workshops indicated in their professional development materials. The Family Engineering kit training took place over a working lunch. To assist in the easy integration and eventual adoption of the materials, researchers selected *EiE*

kits matched to Oklahoma grade-level science standards. Second and third grade teachers received training on the *Best of Bugs: Designing Hand Pollinators* (August; n = 10) or *Catching the Wind: Designing Windmills* (January; n = 10). Fourth and fifth grade teachers received training on *Water, Water Everywhere: Designing Water Filters* (August; n = 10) and *No Bones About it: Designing Knee Braces* (January; n = 9). Although the kits were different according to training session and grade level, it is important to note that *EiE* workshops emphasize that although the science content may change from one *EiE* curriculum kit to the next, the philosophies behind understanding the nature of technology and the engineering design process are consistent across kits. Further, each *EiE* curriculum kit follows the same structure, which makes it easy for teachers to learn one kit and then translate this knowledge to another. To maximize shared resources, the purchased kits and refill materials were made available for checkout at the Interlocal Cooperative so participating teachers could continue to implement the lessons with their 2nd-5th grade students after the funding period.

A goal of the workshop was to enhance teacher self-efficacy in terms of teaching engineering education. Following the suggestions of Cunningham & Carlsen[31], we (a) engaged the teachers in engineering practices by leading teachers through engineering design challenges; (b) modeled pedagogies to support the teaching of engineering practices by providing a safe environment for teachers to wear both a “student hat” and a “teacher hat” as they came to us as novices in teaching about engineering practices; (c) developed teachers understanding of the concepts and connections between science and engineering as we emphasized the differences between the two and provided opportunities for teachers to apply engineering problems in the context of a science discipline; and (d) helped teachers see engineering as a social practice as we modeled collaborative learning in small group settings working through the engineering design process. During the workshop sessions, all teachers completed the introductory "What is Technology?" and “What is Engineering?” training. Then teachers were divided into grade-level groups, 2nd/3^{rd,} and 4th/5th. The teachers engaged in all the activities in each kit as their students would. Facilitators used the "basic" *EiE* teacher training materials, engaging teachers as both learners (student hat) and facilitators (teacher hat) throughout the day. Following the workshop, the participating teachers received a stipend incentive for completing the *EiE* curriculum in their respective classrooms. Teachers were not required to implement the *Family Engineering* activities, although some schools did hold *Family Engineering* nights following the workshop.

Instruments

In order to assess changes in participants’ understandings of engineering education, we utilized existing assessments from *Engineering is Elementary* curriculum kits and INSPIRE at Purdue.[39,49] Researchers used multiple pre- and post- measures to gauge changes on both teachers’ and students’ knowledge and perceptions regarding engineering, as well as to measure changes in teachers’ self-efficacy of teaching engineering. Specifically, the “What is an Engineer?” and “What is Technology?” tests measured changes in teachers’ and student’s understandings of the work of engineers and the human-designed world.[27,49] Additionally, elementary students completed an "Engineering Attitudes" questionnaire to measure attitudes about and interest in engineering careers.[50] This survey included twenty 5-point Likert-type items ranging from strongly disagree (1) to strongly agree (5) with 3 job-related subscales related to the work of engineers: Inventing (defined as interest in jobs and activities that involve

inventing and building/designing cars and buildings), Helping (defined as interest in jobs and activities that involve helping people and the environment), and Figuring things Out (defined as an interest in jobs and activities that involve figuring out how things work). Finally, researchers employed the "Teaching Engineer Self-efficacy Scale" (TESS) to assess changes in teachers' self-efficacy in their ability to teach engineering concepts.[39] In addition to providing an overall teaching engineering self-efficacy scale, the TESS contains 4 subscales: Engineering Pedagogical Content Knowledge Self-efficacy subscale *(KS; 9 items)*; Engineering Engagement Self-efficacy subscale *(ES; 4 items)*; Engineering Disciplinary Self-efficacy subscale *(DS; 5 items)*; and the Engineering Outcome Expectancy subscale *(OE; 5 items)*.

Data Collection and Analysis

Researchers utilized a pre/post design in that we collected baseline data from the participants on the first day of the training. Pre-data was collected at the beginning of the day and the post-measures at end of workshop training. A graduate research assistant and a regional cooperative staff member collected pre/post data from elementary students prior to and following the teachers' implementation of the *EiE* curriculum in the classroom. Researchers removed all identifiers from data, assigned each participant a code, and then entered data into IBM SPSS Version 21.0. Researchers utilized paired-samples t-tests to detect differences between pre- and post- measures.

Results

Findings from the analyses are presented in the sections below. Results from both the teacher participants and their students are presented, respectively.

In-service teachers. Table 1 provides summary statistics on changes in in-service teachers' scores on the multiple measures. In-service teachers made statistically significant gains on all measures. Application of paired-samples t-tests shows that there are some statistically significant changes in the distribution of *What is an Engineer?* ($t(38) = 2.622$, $p = .013$, $r^2 = .29$) and *What is Technology?* ($t(38) = 3.943$, $p < .001$, $r^2 = .15$). Overall, preservice teachers made statistically significant gains in their self-efficacy of teaching engineering ($t(38) = 6.988$, $p < .001$, $r^2 = .56$) and on all of the TESS subscales.

TABLE 1. Summary statistics for in-service teachers' (n=39) pre- and post-measures

	Pretest		*Post-test*				
Subscale	***M***	***SD***	***M***	***SD***	***t(38)***	***p***	***r^2***
What is an Engineer?	75.57	15.86	81.51	16.19	2.622	.013	.29
What is Technology?	87.44	16.10	97.18	6.57	3.943	<.001	.15
Teaching Engineering Self-Efficacy Scale (TESS)-Overall	16.66	3.29	20.57	2.28	6.988	<.001	.56
KS	3.28	1.07	5.01	.733	10.537	<.001	.75
ES	4.67	1.13	5.37	.711	3.646	.001	.26

DS	4.79	1.06	5.32	.741	3.285	.002	.22
OE	3.92	1.13	4.88	.796	4.891	<.001	.39

Note: KS – Engineering Pedagogical Content Knowledge Self-efficacy subscale; ES – Engineering Engagement Self-efficacy subscale; DS – Engineering Disciplinary Self-efficacy subscale; OE – Engineering Outcome Expectancy subscale

Elementary students. Table 3 provides summary statistics on changes in elementary students' scores on the multiple measures. The scores reported here only reflect students who participated in the Fall 2013 semester. Elementary students made statistically significant gains on all measures. Application of paired-samples t-tests shows that there are some statistically significant changes in the distribution of What is an Engineer? ($t(241) = 13.736$, $p < .001$, $r^2 = .44$) and What is Technology? ($t(241) = 19.794$, $p < .001$, $r^2 = .62$). Overall, elementary students made statistically significant gains in attitudes towards engineering ($t(241) = 4.571$, $p < .001$, $r^2 = .08$) and on all subscales.

TABLE 3. Summary statistics for Fall 2013 elementary students' (n=242) pre- and post-measures

	Pretest		*Post-test*				
Subscale	***M***	***SD***	***M***	***SD***	***t(241)***	***p***	r^2
What is an Engineer?	36.99	15.35	64.03	26.70	13.736	<.001	.44
What is Technology?	51.07	13.16	80.68	22.08	19.794	<.001	.62
Engineering Attitude	53.80	13.50	57.78	14.21	4.571	<.001	.08
Overall							
Jobs	27.83	8.89	29.98	8.13	3.678	<.001	.05
Inventing	8.57	3.46	9.04	3.52	1.964	.051	.02
Helping	8.76	3.40	9.69	3.32	3.918	<.001	.06
Figuring Things Out	10.51	4.86	11.26	3.18	2.282	.023	.02

Discussion and Conclusion

The overall purpose of this study was to meet the need for elementary teacher engineering education in rural Oklahoma by providing a comprehensive engineering education curriculum-training workshop and supplying shared resources for classroom implementation. The *RREE* project aimed to increase teacher engineering education self-efficacy and thus student understanding about and interest in engineering processes and careers. With regard to program effects on individuals' knowledge and perception of engineering, all teacher and student participants made significant gains in knowledge of conceptions of technology and the work of an engineer as indicated by statistically significant increases in scores on the "*What is Technology?"* and "*What is Engineering?"* measures. Additionally, the findings from this study indicated that the *RREE* program resulted in statistically significant increases in teachers' self-efficacy of teaching engineering. Further, the findings indicated that the students of RREE program teachers made statistically significant increases in their overall attitudes towards engineering. Overall, the findings from this study indicate that even a one-day professional development training on engineering education can impart changes on teachers' ability to understand and teach about engineering. Further, with the professional development they

received, the teachers were able to positively change their own students' understandings of and attitudes about engineering.

The findings from this study imply that professional development providers need to continue to find ways to provide engineering education training to elementary teachers. Further, due to their geographic isolation and limited access to specialized professional development and STEM teaching materials, administrators and professional development providers must seek out ways to assist rural elementary educators in getting the types of training and materials that they need to be successful in teaching engineering in their schools. Using an interlocal rural school cooperative in our study proved to be a successful model in bringing rural schoolteachers together for training and providing a central location for material storage and distribution.

Generalization of these findings are limited given the small sample size. However, the researchers speculate that teachers in other rural schools would have the same outcomes given similar training and support. Given the limited literature on engineering education in rural elementary settings, more research is warranted on elementary teachers and students' perceptions of engineers and engineering. Further, longitudinal studies of how the training effected teachers' practices would be of interest to the engineering education community.

Overall, the *RREE* proved successful in its mission to expose teachers and students in rural Oklahoma to engineering practices, the engineering design process, and types of engineering careers. Our results indicate that teachers and students made significant gains in their understanding about engineering across most measures. In-service teachers made significant gains in the self-efficacy of teaching engineering. Although funding for the *RREE* program expired, (a) the researchers continue to offer engineering education professional development as requested by school districts and through local workshops and (b) personnel at the Interlocal Cooperative report that teachers continue to check out the *EiE* kits to use in their classrooms. The *RREE* kit check-out system at a centralize location was intended to facilitate continued engagement and shared resources across the Interlocal Cooperative. Next steps for the *RREE* research team are to focus on follow-up data with those teachers who participated in the program to report on their implementation of the engineering curriculum in the classroom, how they and their students received the curriculum, whether they continue to utilize the *EiE* curriculum in the classroom, and assess their current professional development needs with regard to engineering education.

With new state science standards that incorporate engineering practices throughout the grades, it is imperative that teachers receive adequate and on-going training in engineering education. For teachers, the *EiE* curriculum training and kits facilitate meaningful elementary engineering education interactions within the context of traditional science and mathematics instruction. Furthermore, research indicates that students cannot aspire to careers of which they are unaware. Findings from this study indicate that exposure to the *EiE* curriculum significantly increased the students' understanding and awareness about the work of engineers. The *RREE* project suggests a viable model for providing STEM-related professional development opportunities for elementary teachers that can be meaningfully impact teacher and student knowledge gain.

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