

ORIGINAL ARTICLE

Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation

Rebekah Hammack¹ | Toni Ivey²

¹Department of Education at Montana State University, Bozeman, Montana

²School of Teaching, Learning and Educational Sciences at Oklahoma State University, Stillwater, Oklahoma

Correspondence

Rebekah Hammack, Department of Education at Montana State University, 112 Reid Hall, Bozeman, MT 59717.
Email: rebekah.hammack@montana.edu

Abstract

Background: The Next Generation Science Standards (NGSS) call for the integration of engineering content and practices in elementary science curricula, yet little is known about elementary teachers' preparedness to do so or their views on teaching engineering.

Purpose/Hypothesis: The purpose of the current study was to explore K-5 teachers' perceptions about incorporating engineering in their classrooms as well as the perceived barriers for doing so.

Design/Method: This study consisted of an online survey including a mix of selected response, Likert, and short answer items, followed by individual interviews and focus group sessions with a subset of survey participants. Descriptive statistics are reported for quantitative survey data. Open-ended survey questions as well as interview and focus group transcripts were inductively coded to identify emergent themes.

Results: Many elementary teachers support the inclusion of engineering in the science standards for elementary grades. Teachers describe a lack of preservice and in-service training, background knowledge, materials, time for planning and implementing lessons, and administrative support as barriers to implementing engineering activities within their classrooms.

Conclusion: While many elementary teachers support the use of engineering activities in their classrooms, there are numerous barriers preventing them from doing so. To ensure that NGSS are incorporated into elementary classrooms as they were intended, elementary teachers must be provided with the necessary training, resources, and support.

KEYWORDS

barriers, elementary school, engineering standards, NGSS, STEM

1 | INTRODUCTION

The National Research Council's (NRC, 2012) framework report details the need to address the leaky pipeline of students who discontinue pursuing science, technology, engineering, and math (STEM), and in particular, engineering. However, we must also focus on educating the masses, or mainline, as all students need to develop a level of technological literacy proficiency (NRC, 2009). As the United States becomes more dependent on technology, education must shift to prepare the nation's

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2019 The Authors. *Journal of Engineering Education* published by Wiley Periodicals, Inc. on behalf of ASEE.

children to become technologically literate adults (mainline), while also providing content knowledge and skills to children who will enter the STEM workforce (pipeline). To address both pipeline and mainline concerns, the Next Generation Science Standards (NGSS) have incorporated engineering practices into K-12 science standards (NGSS Lead States, 2013). Because NGSS calls for K-12 science teachers to integrate engineering into their classrooms, action must be taken to ensure teachers are prepared to implement the NGSS successfully. Little is known about the preparedness of elementary teachers to incorporate engineering practices into their science lessons. The importance of identifying and responding to teachers' needs has garnered increasing media attention due in part to the recent teacher walkouts seen in multiple states including Oklahoma (Pasquantonio, 2018) where the current study took place. Determining what perceptions elementary teachers hold about K-5 engineering and the barriers they believe limit their abilities to implement engineering standards is necessary to ensure elementary teachers receive the professional training and support needed to implement the engineering components of NGSS.

2 | PURPOSE OF THE STUDY

The purpose of this explanatory sequential mixed methods study (Creswell & Plano Clark, 2011) was to identify the perceptions elementary teachers have about K-5 engineering and any barriers they believe might prevent them from successfully teaching engineering in their classrooms. In particular, the researchers sought to answer the following research questions:

1. What perceptions do in-service elementary teachers hold about implementing engineering education at the K-5 level?
2. What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

3 | RELATED LITERATURE

The need to create both a STEM pipeline and mainline make the incorporation of engineering into the K-12 classroom important. Many students begin making decisions about career paths prior to middle school (Wyss, Heulskamp, & Siebert, 2012), emphasizing the importance of exposure to STEM activities and careers during elementary grades. The integration of engineering standards in NGSS implies that K-5 educators should incorporate engineering in their science curricula; however, K-5 engineering education is a relatively new field of study.

3.1 | Developmental appropriateness of K-5 engineering

Children are born with a natural desire to figure out how things work and design their own creations (C. Cunningham, 2009). The fundamental activity of engineering is design, which naturally permeates children's lives (Petroski, 2003), and in their position paper on engineering in P-12 classrooms, Brophy, Klein, Portsmore, and Rogers (2008) suggest that children are capable of successfully working through the design process. Berry III et al. (2010) describe engineering design as a pedagogical approach to motivate learning in the elementary classroom. In a multi-year field test of the Engineering is Elementary (EiE) curriculum, Lachapelle et al. (2011) reported that teachers in classrooms where this curriculum was being used reported high levels of student engagement during engineering design lessons. Berrett (2006) reported that while some engineering concepts may be more challenging for children to understand, such as optimization and robust design, elementary students do have the ability and interest to benefit from engineering curriculum. Further, Perrin (2004) reported that K-4 students are able to question and investigate the world around them and have the motor skills needed to use measurement tools and complete engineering activities.

If presented in the right way with the correct support structures, engineering is developmentally appropriate for children, and they can engage in sophisticated design challenges well before young adulthood (English & Mousoulides, 2011; Schunn, 2009). C. Cunningham (2009) reported that students who participated in the EiE curriculum developed for use in grades one through five had an improved understanding of engineering, technology, and science as a result of their engagement in engineering activities. Likewise, Yoon, Dyehouse, Lucietto, Diefes-Dux, and Capobianco (2014) reported that second to fourth grade students whose teachers used integrated science, engineering, and technology (STE) lessons had significant content knowledge gains related to STE when compared to a control group. Further, using design to teach mathematics and science can enhance children's communication and spatial reasoning skills and their abilities to develop cognitive models of systems, synthesize information, and conduct experiments (Brophy et al., 2008).

After engaging 120 fourth and fifth graders in multiple rounds of metacognitive reflection over the engineering design process, Purzer, Duncan-Wiles, and Strobel (2013) concluded that elementary students were able to understand the concept of

balancing tradeoffs with regard to optimizing design decisions. Further, the engineering-focused Douglas L. Jamerson Elementary School in Pinellas County, Florida, has seen significant gains in state reading and mathematics scores and a decrease in discipline issues by using an all engineering-focused curriculum (Barger, Gilbert, Poth, & Little, 2006). It is important to note, however, that this is a small study of one program that is still young and the results should not be heavily relied upon until further data are collected.

Information on the developmental appropriateness of engineering in the K-5 grades can also be gleaned from the design and technology movement in the United Kingdom, Canada, and Australia. In the United Kingdom, Key Stage 1 (KS1) corresponds to grades K-1 in the United States, while Key Stage 2 (KS2) corresponds to grades two through five. In a longitudinal study of problem solving strategies used by children, Roden (1999) reported KS1 children are able to make use of a range of resources to apply collective problem solving strategies across a variety of tasks. These results complement those of Constable (1994), who reported children begin developing fine motor skills long before entering KS1 and, thus, are able to use tools (provided they are the correct size and weight) to engage in design activities such as cutting and joining. Constable (1994) also reported KS1 and KS2 children are able to use a variety of drawing techniques to convey their ideas, yet Hope (2000) cautions children may not be fully able to use drawings as a way to plan a design yet to be constructed.

In an Australian study of 16 three- to five-year-old children who attended the same child care center, Flear (2000) reported that young children were able to progress from oral planning to two-dimensional sketches of their designs; however, most children had difficulty using their drawings to guide construction, possibly due to the lack of detail and the limitations of a single front view drawing. This ability to communicate design ideas orally and in two-dimensional drawings is in contrast to Hill and Anning's (2001) finding that 4- and 5-year-old students in Canadian and English classrooms had trouble with both of these skills. Further, Hill and Anning (2001) reported 4- and 5-year-olds' choices of materials to build with were based on the materials' aesthetics rather than the materials' properties, resulting in designs that did not hold up after use. In a quasi-experimental study of urban first grade students in the United States, Portsmore (2010) reported that first grade students' experiences with materials impacted their abilities to construct solutions to design problems. Students were better able to create successful design solutions using materials they had previous experience with. Portsmore (2010) also found that given the proper scaffolding, first graders were able to solve design problems with up to six design requirements.

3.2 | Barriers to teaching K-5 engineering

In their position paper on K-12 engineering education, Brophy et al. (2008) describe teachers as being uncomfortable teaching what they do not know or are unfamiliar with. Many prekindergarten through eighth grade teachers have limited STEM content knowledge (Brophy et al., 2008), a limitation which may result in their avoiding teaching engineering. The familiarity with engineering construct is not well developed in the literature and consists primarily of studies using an instrument developed by Yasar and colleagues. Yasar, Baker, Robinson-Kurpius, Krause, and Roberts (2006) used a Likert scale instrument with 98 Arizona K-12 teachers (61% taught K-8) to measure participants' familiarity with engineering, engineering design, and technology (DET). Most teachers in the study had little familiarity with DET, which they attributed to lack of knowledge, lack of administrative support, lack of training, and lack of time for learning about DET. In a subsequent study by Hsu, Purzer, and Cardella (2011), 192 elementary teachers from 18 states were given the DET prior to participating in a summer professional development (PD) program held at Purdue University. These researchers reported findings similar to Yasar et al. (2006).

After completing a survey study of 43 middle school teachers, Van Haneghan, Pruet, Neal-Waltman, and Harlan (2015) found that successful implementation of engineering design curricula is influenced by a teacher's beliefs about his or her knowledge and skills as well as resource availability. The development of a teacher's engineering education expertise is a long process, and it can take from 3 to 6 years for teachers to feel comfortable implementing engineering activities (C. M. Cunningham & Carlsen, 2014). After evaluating lesson plans from 42 K-12 teachers in Idaho, Nadelson, Sias, and Seifert (2016) reported teachers are likely to have a constrained view of engineering and lack the knowledge and skills needed to implement the innovative pedagogical methods associated with teaching engineering at the K-12 level. Further, elementary teachers from two schools in south-central United States who participated in a case study conducted by Douglas, Rynearson, Yoon, and Diefes-Dux (2016) indicated constraints on instructional time and administrator focus on standardized testing were barriers to implementing engineering activities in the classroom.

Although the literature is limited in regard to the barriers to implementing engineering in the elementary classroom, the research community is better informed about the barriers to implementing science in the elementary curriculum. Studies aimed at describing the barriers to implementing inquiry science at the elementary level report barriers that cut across contexts (e.g., school location, grade level taught, years of teaching experience) and include a lack of content knowledge (Burton & Frazier, 2012; Sexton,

Atkinson, & Goodson, 2013); inadequate preservice training (Blanchard, Osborne, Wallwork, & Harris, 2013); and a lack of resources, planning time, and instructional time (often due to a focus on tested subjects) (Blanchard et al., 2013; Cartwright, 2014; Santau & Ritter, 2013). Further, based on survey responses from 977 K-12 teachers in North Carolina, Blanchard et al. (2013) reported teacher comfort related to inquiry teaching methods was the most significant variable in determining whether teachers would teach using inquiry. Similarly, when interviewing award-winning science teachers from grades K-12, Burton and Frazier (2012) found that all respondents said elementary teachers lacked the content and pedagogical content knowledge required to teach science through inquiry and that many were intimidated by inquiry and avoided teaching using it.

Overall, the literature devoted to the developmental appropriateness of teaching engineering at the elementary level reveals that elementary students are capable of participating in and learning from engineering activities. The barriers teachers have related to implementing these activities at the elementary level need to be fully explored to ensure teachers are given adequate support for engineering classroom implementation. The current study adds to this area of literature by describing the barriers K-5 teachers perceive as limiting their abilities to teach engineering to their students and offering suggestions for easing these barriers.

4 | METHODOLOGY

This study is part of a larger study (Hammack, 2016) investigating Oklahoma elementary teachers' perceptions of engineering and engineering design and their preparedness to teach engineering. A preliminary version of this work was presented at the 2018 American Society of Engineering Education Annual Conference (Hammack, 2018). During the first phase of the current study, participants completed an online questionnaire including selected response, open-ended, and Likert questions. Results from Phase 1 were used to finalize the interview protocols used during Phase 2 of the study. Results from both phases were merged and used to answer the research questions (Creswell & Plano Clark, 2011).

4.1 | Oklahoma academic science standards

In March 2014, Oklahoma adopted new science standards (OAS-S) that went into effect beginning in the 2014–2015 school year, with all state science assessments being aligned to OAS-S beginning in the 2016–2017 school year. Data for the current study were collected in 2015, after the adoption of OAS-S but prior to the alignment of state assessments to OAS-S. OAS-S mirror NGSS with the inclusion of engineering practices beginning in kindergarten, meaning that at the time study data were collected, participants should have been incorporating engineering in their classrooms if they were implementing OAS-S as prescribed.

4.2 | Participants

A database containing contact information for Oklahoma K-5 public school teachers ($n = 16,546$) was obtained from the Oklahoma State Department of Education (OKSDE). A link to the questionnaire was emailed to all teachers in the database; however, 1,008 emails were returned undeliverable. The questionnaire (Phase 1) was completed by 542 participants who were responsible for the science instruction of their students, resulting in a 3.5% response rate. Follow-up focus group and interviews sessions (Phase 2) were completed by 2.76% of the Phase 1 participants.

OKSDE has assigned each Oklahoma school district to one of eight geographic regions, called Reac³h regions (OKSDE, 2014). The state covers a large geographic area including urban, suburban, and rural populations, and the Reac³h Region of participants was used to determine the geographical representativeness of the sample. Tables 1 and 2 present demographic information for the sample. A review of the sample and state K-5 teaching population indicate the percentage of participants identified in each demographic subcategory fell within a few percentage points of the corresponding state population demographic with a few exceptions. Region 3 was overrepresented by 8%; participants holding Master's degrees were overrepresented by 8% while participants with Bachelor's degrees were underrepresented by 8%; and traditionally certified participants were underrepresented by 5% while participants with alternative certification were overrepresented by 5%.

Overall, these data suggest the sample closely mirrors the state population with regard to gender, grade level taught, years of teaching experience, and geographic distribution of teachers (with the exception of Region 3). OKSDE does not collect information about the Title I status of schools; however, the sample contains teachers from both Title I and non-Title I schools. Survey participants did not specify the type of classroom in which they taught; however, follow-up participants included a mix of self-contained, departmentalized, and special education teachers.

TABLE 1 Demographics of Oklahoma K-5 teacher population and study sample

	Population		Sample			
			Phase 1		Phase 2	
	Number	Percentage	Number	Percentage	Number	Percentage
Oklahoma Reac ³ h region ^a						
1	670	4.03	26	4.80	1	6.67
2	1,181	7.10	48	8.86	1	6.67
3	3,538	21.28	159	29.34	6	40.00
4	2,180	13.11	55	10.15	1	6.67
5	1,049	6.31	18	3.32	1	6.67
6	1,384	8.32	37	6.83	0	0
7	1,058	6.36	30	5.54	1	6.67
8	5,567	33.48	169	31.18	3	20
Gender						
M	698	4.20	16	3.00	0	0
F	15,929	95.80	526	97.00	15	100
Highest education level						
Bachelor's	13,090	78.73	381	70.30	10	66.67
Master's/Ed. specialist	3,498	21.04	157	28.97	5	33.33
Doctorate	36	0.22	4	0.74	0	0
Not applicable	3	0.01	0	0.00	0	0
Teaching experience (years)						
1 to 5	4,926	29.63	163	30.07	6	40.00
6 to 10	3,501	21.06	111	20.48	3	20.00
11 to 15	2,506	15.07	85	15.68	0	0
16 to 20	2,224	13.38	69	12.73	3	20.00
21 to 25	1,613	9.70	48	8.86	1	6.67
Over 25	1,857	11.17	66	12.18	2	13.33
Teacher certification type						
Traditional	15,951	95.93	491	90.59	12	80.00
Nontraditional	676	4.07	51	9.41	3	20.00
Grade level taught						
K	3,176	19.10	91	16.79	4	26.67
1	3,638	21.88	98	18.08	2	13.33
2	3,601	21.66	102	18.82	4	26.67
3	3,658	22.00	112	20.67	1	6.67
4	3,370	20.27	120	22.14	5	33.33
5	3,527	21.21	98	18.08	1	6.67

^aThe Oklahoma Reac³h regions were used to determine the geographical representation of the state. A map of the Reac³h regions can be found at <http://ok.gov/sde/reac3h-network>.

4.3 | Researcher stance

As a middle school engineering teacher certified through Project Lead the Way (PLTW), the first author came to the study with preconceived ideas about responses, expecting participants to have limited experiences with engineering and hold

TABLE 2 Ethnicity and Title I school status of study participants

	Phase 1 number	% of Phase 1 participants	Phase 2 number	% of Phase 2 participants
Do you teach in a Title I school?				
Yes	432	79.70	13	86.67
No	84	15.50	2	13.33
Do not know	26	4.80	0	0
Ethnicity				
African American	5	0.92	0	0
American Indian or Alaskan native	42	7.75	1	6.67
Hispanic	13	2.40	2	13.33
Asian or Pacific islander	4	0.74	1	6.67
White	453	83.58	11	73.33
More than one	16	2.95	0	0
Other	8	1.48	0	0

preconceived notions about engineers, just as the researcher did prior to teaching engineering for the first time. The researcher acknowledged these preconceived ideas and remained open and true to the data that emerged.

The second author, a science educator whose research focuses on engineering education, anticipated that the participants would have naive conceptions about engineering and engineering design. The second author recognized these preconceived ideas and actively worked to remove personal bias while analyzing the data.

4.4 | Measures

No individual questionnaire existed to address all the research questions that were part of the study. As a result, subscales were combined from existing instruments to gather data pertinent to all research questions. The separation of different subscales is common in education fields, as seen with the use of individual subscales from the Fennema–Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976), which have been validated when used as a whole (Broadbooks, Elmore, Pedersen, & Bleyer, 1981) or in part (O'Neal, Ernest, McLean, & Templeton, 1988). Specifically, the questionnaire items analyzed during the current study included (a) the Barriers to Integrating DET subscale from the Design Engineering and Technology Survey (Hong, Purzer, & Cardella, 2011) and (b) modified versions of several questions from the Texas Poll of Elementary School Teachers (J. McNamara, 1999, 2000; J. F. McNamara et al., 1998). See Appendix A for a full list of survey questions used in this study.

4.4.1 | Design Engineering and Technology Survey

The DET, originally developed by Yasar et al. (2006) and re-evaluated by Hong et al. (2011), is a 40-item, 5-point Likert instrument used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. The original instrument was completed by 97 Arizona 1–12 grade teachers (61% teaching grades 1–8) and consisted of 41 items (Cronbach's $\alpha = 0.88$) that explained 43.5% of the variance and loaded four factors—Importance of DET (18 items, $\alpha = 0.91$), Familiarity with DET (12 items, $\alpha = 0.83$), Stereotypical Characteristics of Engineers (5 items, $\alpha = 0.76$), and Characteristics of Engineers and Engineering (6 items, $\alpha = 0.66$). Hong et al. (2011) re-evaluated the DET using a sample of 192 elementary teachers from 18 U.S. states. The resulting instrument contained 40-items (Cronbach's $\alpha = 0.88$) that explained 74% of the variance and loaded on four factors—Importance of DET (19 items, $\alpha = 0.91$), Familiarity with DET (8 items, $\alpha = 0.81$), Stereotypical Characteristics of Engineers (7 items, $\alpha = 0.77$), and Barriers to Integrating DET (6 items, $\alpha = 0.68$).

Prior to data analysis in the current study, the internal consistency of the Barriers to Integrating DET subscale was determined by calculating a Cronbach's α value ($\alpha = 0.63$), which was slightly lower than the value reported by Hong et al. (2011).

4.4.2 | Texas Poll of Elementary School Teachers

The Texas Poll of Elementary School Teachers was a phone interview questionnaire designed to gather information that could be used to improve science teaching at the elementary level (J. McNamara, 1999; J. F. McNamara et al., 1998). A two-stage cluster sampling design was used to select 200 elementary teachers for this telephone survey. The study had an 88% response rate, resulting in 175 participants. The telephone questionnaire included 27 items, four open-ended and 23 closed-ended questions. The reported findings were descriptive in nature.

For the current study, Questions 3, 4, 5, 6, 9, 10, 26, and 27 of the Texas Poll were included in the online survey and modified by replacing the word *science* with *engineering*. For example, Item 3 on the Texas Poll “Do you believe science is a high priority in your school?” was changed to “Do you believe engineering is a high priority in your school?” The majority of the Texas Poll questions were selected response, with three of the questions followed with “Please elaborate on your previous response.” The questions including follow-ups were “Are you satisfied with the extent to which your school provides you with instructional materials to teach engineering? Please elaborate on your response.” “What are the two most important things that would help you improve engineering teaching in your classroom. Please elaborate on your response.” and “Assume you have been appointed to a national task force that wishes to construct a new preservice teacher methods course devoted explicitly to teaching engineering in elementary schools. What two things would you recommend they stress in developing this new preservice course? Please elaborate on your response.”

4.5 | Data analysis

Data from the questionnaire were analyzed during Phase 1. Interview and focus group data collected during Phase 2 were analyzed independently and then merged with the Phase 1 data.

4.5.1 | DET analysis

Participant responses for the DET subscale were transferred to SPSS Version 22. Researchers analyzed data to yield frequencies of responses to each subscale question.

4.5.2 | Texas Poll analysis

All selected response questions were transferred to SPSS and analyzed to yield frequencies for how many participants chose each response category. Responses to the three open-ended questions were printed onto cards which were used during the coding process (Creswell, 2007). First, attribute coding was used to log essential demographic information about the participants for future reference (Saldana, 2013). Each card was coded with the participant's gender, ethnicity, years of teaching experience, education attainment level, geographic region, pathway to certification, and grade level taught. The researchers then read through each response and compiled an initial list of codes to use during coding. Next, the researchers used the initial code list to complete a round of descriptive coding as described by Saldana (2013). During this initial round of descriptive coding, additional codes were generated and added to the preliminary code list and code frequencies were determined. The frequencies with which each code appeared in the data were based on the number of participants who used a particular code, not the number of times that the code appeared (Namey, Guest, Thairu, & Johnson, 2008).

4.5.3 | Focus groups and interviews

After completing the online questionnaire, participants were redirected to an unlinked survey where they could voluntarily provide contact information to participate in a follow-up interview or focus group. Volunteers were given the option of three cities in different geographic locations where focus groups could be conducted. Individuals were also offered the option of participating in an individual face-to-face, Skype, or telephone interview. Based on individual availability, three focus groups were scheduled in two different large cities in the state. Seven to ten individuals were scheduled for each session; however, actual focus group attendance was low, with four individuals participating in the first focus group and the last two focus group sessions becoming individual interviews. A total of 11 individual interviews were conducted: two in person and nine over the phone. Protocols for the interview and focus group sessions are in Appendices B and C, respectively. Interview questions were developed in the hopes of eliciting responses that would help answer the research questions. All follow-up sessions were conducted by the first author, who also audio-recorded the session. Immediately following each follow-up session, the first

author reviewed the field notes and wrote a reflection about the session. Demographic information for focus group and interview participants is presented in Tables 1 and 2.

All focus group and interview sessions were transcribed verbatim by the first author who conducted the session (Oliver, Serovich, & Mason, 2005). Each participant was provided with a copy of the transcript to allow for member checking and to ensure that the findings remained true to the participants' perspectives, and changes were made to the transcripts based on their feedback. Pairings of interview questions were used to gain a deeper understanding of participants' views related to specific research questions. The first author inductively analyzed the data by attempting to make sense of the data without imposing predetermined expectations (Patten, 2001). First, the first author conducted an initial read through of the transcripts, during which a list of codes was generated. During a second reading of the transcripts, codes were examined to identify patterns and themes. Finally, patterns and themes related to each research question were identified, explored, and triangulated with Phase 1 data in order to answer each research question.

4.6 | Trustworthiness and credibility

In the current study, the researcher was open with participants about the nature of the study and provided them with the opportunity to review her written description and interpretation of the interviews and focus group sessions. The themes emerging from the interview and focus group sessions were compared with the information obtained from the questionnaire responses and analysis to allow for triangulation (Gall, Gall, & Borg, 2003). The researcher also established inter-rater reliability by having the second author independently analyze the transcripts and then comparing the resulting codes. Any discrepancies between codes were discussed until consensus was reached.

5 | RESULTS

When answering the research questions, the researchers analyzed the quantitative and qualitative data separately and then merged the two to come to a deeper understanding of the underlying phenomena. The findings are presented in a similar manner, with qualitative and quantitative findings reported separately in Section 5 and then merged in Section 6.

5.1 | Quantitative findings

During Phase 1, the Barriers to Implementing DET subscale data and the responses to the modified Texas Poll questions were analyzed. Figure 1 displays participant responses to the DET subscale questions, each of which measures the strength of a barrier to teaching engineering based on the perception of our participants. The majority of participants strongly agreed that lack of time to teach DET (57%), lack of teacher knowledge of DET (50%), and lack of training in DET (57%) are barriers to implementing engineering in their classrooms. While administrative support was also reported as a barrier by approximately half of the participants, it was not reported as a strong barrier as frequently as the others.

When asked if participants had attended engineering-focused PD during the last 3 years, 85% reported that they had not. Of the 15% who had attended, only 40% reported that their districts paid for them to do so. Examples of engineering-focused PD that participants attended included PLTW, STEM workshops developed by local organizations, and robotics trainings such as

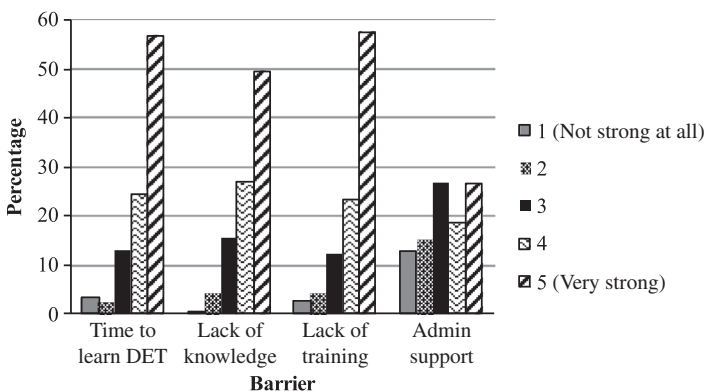


FIGURE 1 Participant responses to items on the Barriers to Integrating Design/Engineering/Technology (DET) subscale

FIGURE 2 Participant responses on the modified Texas Poll related to perceived priority level of engineering

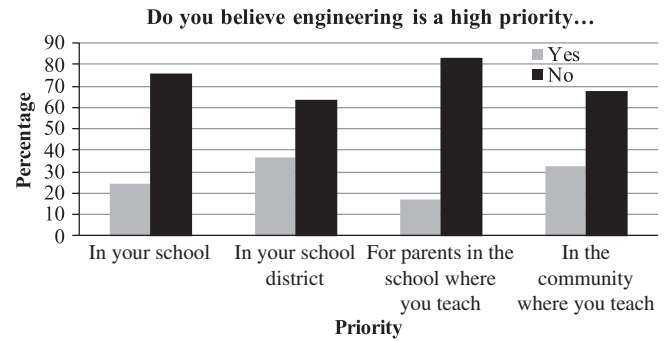
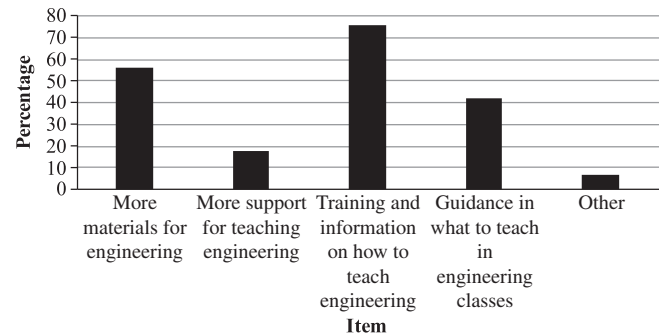


FIGURE 3 Items identified by K-5 in-service teachers as important for improving engineering teaching



Botball and For the Inspiration and Recognition of Science and Technology (FIRST) Lego League. Many participants could not remember the name of the PD they had attended and simply called it a STEM training.

Figure 2 displays participant responses to the modified Texas Poll question “Do you believe engineering is a high priority?” Overall, participants did not believe that engineering was a priority in their schools, in their school districts, to the parents in their schools, or to the communities where their schools were located.

When asked if they were satisfied with the extent to which their school provides instructional materials for teaching engineering, 81% of the participants said they were not satisfied. Interestingly, of the 103 (out of 542) participants who were satisfied, 35% commented that their district did not provide any resources, but because they do not teach engineering, they have no need for instructional materials. Those who stated that they were unsatisfied mentioned that there was too much emphasis placed on reading and mathematics, so materials and training for science and engineering were not offered. One participant wrote, “There is really nothing provided and for the most part it boils down to ‘it’s not tested in my grade, so don’t spend too much time on it.’” Another wrote, “As far as I know, we have no support in this. We do not even have sufficient support in science.... The last time we received new teaching materials was in the 1990s. I am also missing one of my science textbooks and have asked for it to be replaced the past 3 years ... hasn’t been replaced yet.”

5.1.1 | Improving ability to teach engineering

Participants were asked to identify the two most important things that would help improve their abilities to teach engineering. Responses are displayed in Figure 3. Training and information about how to teach engineering was the most commonly selected item (76%), followed by additional materials (56%), guidance in what to teach in engineering classes (42%) and support for teaching engineering (18%). Nine percent of participants selected “other” and listed additional time for planning and/or teaching engineering as an area for improvement.

5.1.2 | Elements of preservice engineering methods course

Participants were also asked to identify the two most important elements that should be included in a preservice engineering methods course and to elaborate on their answers. Figure 4 illustrates participants' responses. How to teach engineering and how to use materials to teach engineering were the most frequently chosen elements. For the “other” category ($n = 28$),

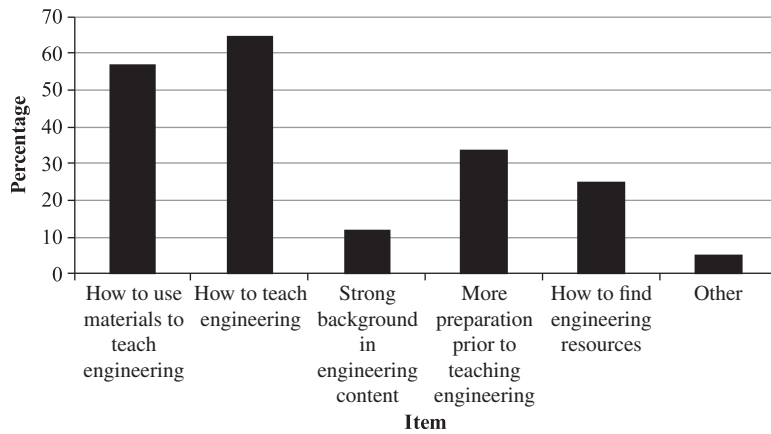


FIGURE 4 Items identified by K-5 in-service teachers as important to include in a preservice engineering methods course

participants listed things like lesson plan ideas, hands-on training, and ideas for funding. Interestingly, one participant who chose “other” wrote, “not important for my grade and social status children.”

5.2 | Qualitative findings

Qualitative data consisted of the elaboration responses on answers to the two Texas Poll questions presented above (improving ability to teach engineering, elements to include in preservice methods) and transcripts and field notes from the Phase 2 interview and focus group sessions. Analysis of the qualitative data resulted in seven categories: materials, support, background knowledge and preparation, time, hands-on and applicable training, focus on testing/micromanagement, and appropriateness of engineering for elementary grades. Many participants' responses fell within more than one category and were counted in each category in which they fell. For each category below, Phase 1 and Phase 2 responses are presented separately.

5.2.1 | Materials

Responses in this category focused on a lack of physical materials or curriculum materials for teaching engineering, how to use materials, and where to find materials and other resources for teaching engineering.

Phase 1

One participant stated, “I don't know of anything in my classroom I could use right now to teach an engineering lesson with.” Another participant wrote, “Without the proper supplies it makes it extremely hard to teach these standards.” Participants also stressed the importance of being trained on how to use materials to teach engineering: “Materials without knowledge about how to use them leads to students not learning, and knowledge without proper materials just scratches the surface with regards to students needing hands-on learning.” Another participant wrote, “Providing materials is not enough. Many rooms have excess materials. Teachers must be taught how to use materials.”

Phase 2

Likewise, Phase 2 participants described a lack of materials as a barrier to teaching engineering: “What I am lacking would be the materials and the textbooks to teach it.” Another stated, “I don't feel prepared. I don't feel like I have the materials to teach it properly.” Another listed both lack of time and resources: “We are so far behind technology wise. It does them no good to read about it if they can't do it hands-on and see how it works. We don't have time and we don't have the resources.” Others focused on the need to know how to locate appropriate resources:

Since engineering is now part of the standards, I think how to teach engineering would be important in a class and since curriculum specifically for engineering will not always (or even usually?) be provided, I think how to find engineering resources and/or how to use other materials to teach engineering would also be important.

Another participant wrote, “Knowing where to find the resources is a very important component in including it in the classroom. When schools do not provide resources, teachers should know how to teach engineering.”

5.2.2 | Support

Responses included in this category related to the lack of administrative support for teaching engineering or the perception that engineering was not encouraged or required to be taught.

Phase 1

One participant stated, "Engineering is not in our PASS skills [state standards] for my grade level. If it was in the PASS we would teach it." One teacher stated, "I haven't even been told we are supposed to teach about this subject." Others mentioned support for teaching engineering to certain groups of students: "Engineering lessons are reserved for students who are a part of the Gifted and Talented program," but not for others since "special education is not encouraged to teach it."

Phase 2

"I need support from my district and that can include financial support or curriculum support." One teacher mentioned the need for long-term support:

They tell us all this stuff that we have to implement and they give us some little workshop which are good for some, and some still don't understand it, but there's not any follow-up to see how things are going.

5.2.3 | Background knowledge and preparation

Responses in this category were related to participants' lack of knowledge of engineering and lack of preservice training.

Phase 1

Participants mentioned the importance of teachers understanding the content knowledge they must teach. For example, "teachers need to understand what you mean by engineering. We try and teach our kids to think, but what type of engineering projects would the state approve as 'good' and teachers think are 'good' could be very different." Another participant wrote, "If teachers don't have background knowledge and understand it themselves, they WILL NOT implement their training in their classrooms!" Other teachers mentioned being intimidated by their lack of engineering knowledge, which resulted in not teaching it: "I don't know. I have no idea about teaching any kind of engineering. I do not attempt nor would I attempt to teach engineering."

Phase 2

Phase 2 participants described lack of knowledge as a reason why they did not feel prepared to teach engineering: "I have not been trained. I feel like I am limited on my knowledge of it so I definitely don't feel like I could teach it, having a limited amount of understanding myself." Another stated, "I don't feel like I have the background knowledge to teach them properly and ... the necessary training to be able to teach them the skills they need to know." Yet, there was one participant who felt background knowledge was not an obstacle, saying "I feel that as far as my understanding of it, I could teach it at a 4th grade level."

Lack of preparation was a common issue:

I don't feel like I'm alone in that I don't feel prepared to teach it. As far as college curriculum, that's not something I took. I think [administrators] need to know that they're asking us to teach something that we've not ever dealt with and unless you're a science or math teacher you might have had some but if you're not then you wouldn't be prepared to teach it. I think they're asking us to do something that we're not prepared to do.

The lack of preservice training was also mentioned:

I think lack of training in colleges and teachers out in practice, there's not a whole lot for science in general. They also need to know that we don't have materials and that without proper materials it's really hard to teach science. If it's not really given to us then it often doesn't get done.

5.2.4 | Time

Responses in this category focused either on lack of time during the school day for teaching engineering or on lack of time for planning and preparing lessons for teaching engineering.

Phase 1

Participants were frustrated with the amount of material to be covered and the lack of time to do it in: “We already have too much on our plate. This would be one more thing.” As another teacher stated, “I don't have time to find materials, produce lessons, and research how to do it all myself.”

Phase 2

One kindergarten teacher described the amount of time it takes to locate your own materials:

You need the supplies to teach some of those things ... some good resources, some place we could go and look online. Time is a big factor when you go looking for something because you could spend hours cruising through YouTube, Pinterest, Teacher pay Teacher. I would love a website where we could go for our science stuff. I could go to science, kindergarten, click on worksheets or activities and recommended reading to go with it.

For this teacher, finding the time to gather quality resources was a considerable barrier to teaching. Another participant explained:

I need time in my schedule to be able to teach it. That's a big piece also, there's so much in the day that we have to do so we have little time for extra things, so I need flexibility to do things too so if there is time provided in my schedule to teach it during the day.

5.2.5 | Hands-on and applicable training

Responses in this category were related to the importance of hands-on training that is applicable to the classroom.

Phase 1

“Preservice teachers need real life experiences in teaching engineering lessons, rather than lectures over the topic.” Another participant wrote:

I would like to be shown explicit ways to introduce and to implement engineering in the classroom. Often times these courses go on and on about what engineering is, but I need to know how to implement it in an elementary classroom. Show me examples of lessons.

Phase 2

“I need training on the materials so I can use them the most appropriately. A lot of times teachers are given things and they sit in a corner if they aren't given the proper training.” Another stated, “[Administrators] need to know that I need training and I wouldn't feel comfortable teaching it without some training.”

5.2.6 | Focus on testing/micromanagement

Responses in this category were related to an overall climate of micromanagement and pressure to focus instruction on high-stakes testing.

Phase 1

Participants said they did not have time to teach engineering because they had to focus on content that would be on state assessments: “[Engineering] is not done in our elementary school for time is spent on focusing on the skills the students will be tested on.” Another participant wrote:

We just do not talk about science much at all. We're pretty much told to focus on math and reading since those are two subject areas we test in each year. We do teach science for half the year, but I don't think the administration cares how, when, or how much it is taught.

Phase 2

Many teachers described the problems with high-stakes tests and how it resulted in only mathematics and reading being priorities: "There's too much emphasis on testing and it's too high stake that it does force us to focus on the tested skills instead of the non-tested ones." "I think [administrators] are aware that we do need to teach the students [engineering] but there's only so many hours in the day and right now as a school we have to get our grades up in reading and math areas." Another mentioned making STEM a priority:

They need to make STEM a priority instead of just saying it. We've concentrated on reading and math necessary in order to do the STEM exercises but our kids are not going to succeed at STEM without a lot of help unless we say it is a priority and we put some bite into it and give schools some money that do it and those who don't, don't [get money].

These quotes illustrate that participants felt the pressures of teaching for the purpose of preparing students for success on mandated state assessments, which left little to no time for teaching other subjects.

Additionally, some participants described a climate of micromanagement and an almost us vs. them attitude: "If the state department understood that we need the resources and we need the time and if they let us do what we know how to do instead of putting all this stuff on us that they think needs to happen." Another teacher seemed frustrated that the state department did not trust her enough to do the job she was hired to do:

I think they have too much. Sometimes I feel like I don't have any say in what I want to teach or how I want to teach it and they're just like you have to do it this way because we're going to check up on you. Give me the freedom. I was hired because you thought I knew how to do my job so let me do my job.

5.2.7 | Appropriateness of engineering for elementary grades

Responses in this category were related to participants' views on the appropriateness of incorporating engineering into the K-5 classroom.

Phase 1

A surprising category to emerge from the survey data was the idea that engineering should not be incorporated into the elementary curriculum. Participants were asked to elaborate on the items they needed to better enhance their abilities to teach engineering and on items to include in preservice course work, so it was expected they would describe items needed to help them teach engineering, yet a few responded by saying that engineering should not be taught in elementary school. One participant stated, "I feel teachers have enough to teach without adding more on our plate, with students that can't even read." Another wrote, "At this age level, I don't understand the need or reason for engineering when basic facts are no longer of importance." Another stated that "I didn't become an elementary teacher thinking I would teach elaborate engineering." Another wrote, "We must stay focused on reading and math basics for the children's sake."

Phase 2

The interview participants felt that engineering had a place in K-5 classrooms but not all shared the same reasons. Some pointed to the importance of early career awareness:

I think it's important for the kindergarten teacher to explore all areas of science and math and all aspects of academic areas because I want my kindergarten students to know all of the different opportunities available to them. I want them to know that they can be anything they want to be and I want them to have a variety of experience and opportunities of different interests so they can learn about different things in different ways. I think there are different ways that you would teach it at the middle school and high school level that are developmentally appropriate, with their skills and their abilities but I definitely think it has a place at the elementary level so that kids can be exposed to a variety of knowledge.

Other teachers mentioned the development of skills that could be used in the future:

I think it's a wonderful thing, some of it's gonna go over their heads but that's in every subject that we do. You're gonna have kids that do great in science but reading they really struggle with. I think it's a wonderful idea because it lights an interest in kids at a young age and can take that and develop skills that they can use as a career path.

Another teacher stated:

They need to know that it's not for every kid but every kid needs to be exposed to it. I think every kid would take away something even if they're not going to be an architect or an engineer. I think the upper grades would appreciate it if we had more things like that at the lower grades.

Still others mentioned the creativity that is innate to children:

I know reading and writing are important but I feel like kids are so creative that if you give them time to think and create things, they really enjoy that so I feel like there needs to be a little more of that and more time for kids to do other things than reading and writing.

While the Phase 2 participants had different views for why engineering should be incorporated into the science standards, none were opposed to the idea.

6 | DISCUSSION

The purpose of this study was to identify the perceptions K-5 teachers hold about engineering education and the barriers they believe prevent them from implementing engineering in the classroom.

6.1 | Research Question 1: What perceptions do in-service elementary teachers hold about implementing engineering education at the K-5 level?

Questionnaire responses indicated that most participants perceived K-12 engineering was not a priority in their schools, school districts, communities, or for the parents at their schools (see Figure 2). Participant comments also suggested they felt engineering was not a priority to administrators and the state department of education. Rather, participants perceived the focus of school administration was on state mandated assessments in mathematics and reading. Similar findings have been reported in the literature related to lack of time for teaching inquiry science due to a focus on mandated tests (Blanchard et al., 2013; Cartwright, 2014).

While analyzing the questionnaire responses, it became clear that, overall, participants were supportive of engineering education. However, it was obvious that participants held misconceptions about engineering which may have influenced their responses. Fewer than 5% of participants did not feel engineering should be included in K-5 curriculum. These responses appeared to be based on a lack of understanding of engineering and the engineering practices described in the NGSS. Comments about engineering being just another topic added onto an already overflowing plate indicate that teachers are unaware of the integration approach taken by the NGSS with regard to engineering (NGSS Lead States, 2013). Engineering practices are woven within the NGSS and linked to science content standards that are already being taught in K-5 classrooms; therefore, the addition of engineering content and practices to NGSS does not add additional requirements to the science standards already being taught. This approach to teaching engineering as a part of science, however, could be new and possibly overwhelming for teachers if they are not provided with adequate support and training. Without this support, they could continue to view engineering as just another thing added to their already full plates. Although the NGSS have not been adopted in Oklahoma, the new OAS-S mirror the NGSS. Further, approximately 2% of participants stated that even though they did not receive any resources for teaching engineering, they were satisfied with this because they did not teach engineering anyway. This response reveals that teachers do not understand the science standards they are required to teach as part of OAS-S, which require them to be engineering teachers.

Participants' responses also indicated teachers held misconceptions about the difficulty or nature of engineering. For example, a few participants mentioned it is not appropriate to teach engineering when they have students who struggle with basic reading and math skills. Again, this response shows a lack of understanding of how engineering can be integrated in the existing curriculum. The incorporation of engineering into lessons has been shown to be an effective way to teach mathematics and improve scores on mathematics achievement tests at the elementary level (Hotaling et al., 2007; Parsons et al., 2007). However, there are mixed findings in the research literature about students' mathematics and science gains with regard to engineering education (National Academy of Engineering and National Research Council, 2014).

Unlike the questionnaire responses, all follow-up participants had positive things to say about including engineering in the K-5 science standards. Multiple participants talked about the importance of career awareness and that students need to be exposed to as many careers as possible when they are in elementary school. Furthermore, participants mentioned the skills students learn from participating in engineering activities would be valuable regardless of their future career paths. Additionally, one participant mentioned the natural creativity elementary students possess and how engineering would be the perfect outlet for building on innate creativity. This match between engineering and children's creativity has been previously supported in the research literature (C. Cunningham, 2009; Petroski, 2003). It is important to note follow-up participants included a very small subset of study participants; therefore, their positive views of engineering education cannot be generalized to the entire population.

Taken together, these findings suggest many elementary teachers support the idea of integrating engineering into the elementary curriculum and view engineering as beneficial to their students. The majority of participants stated that if they were given the training and materials they would enjoy teaching engineering to their students. However, some Phase 1 participants did not see the value of incorporating engineering education at the elementary level. It is important to note, however, that a lack of understanding of how the engineering standards are designed to be implemented and the perceived lack of priority that has traditionally been placed on engineering at the elementary level may have impacted teachers' views relative to both sides of this issue.

6.2 | Research Question 2: What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

As expected, the barriers reported in the research literature related to teaching inquiry science were similar to those identified in the current study, namely lack of time (Cartwright, 2014), lack of knowledge (Sexton et al., 2013), lack of training (Blanchard et al., 2013), and lack of resources (Cartwright, 2014). Many of the issues related to these barriers are overlapping, such as lack of time to find materials or lack of training on how to use materials.

Participants stated they did not have enough time in the school day to teach all of the required curriculum components. They reported that the majority of the school day was devoted to mathematics and reading due to associated mandated testing in those areas, and science was often only incorporated into reading time or was completely left out. Similar findings have been reported pertaining to teaching engineering (Douglas et al., 2016) and inquiry science (Blanchard et al., 2013; Santau & Ritter, 2013). Lack of time for planning was another common barrier. Teachers spend hours planning before they teach a new lesson. They take time to research and go over the content to make sure they fully understand it, gather and set up materials, and create assessments for the lesson. Further, the fewer resources teachers have for a particular topic, the more time they must spend planning for those lessons by searching for and gathering curriculum resources. Elementary teachers plan lessons for multiple subjects, a process which takes a significant amount of time each week. This reality, coupled with the fact that most teachers do not have engineering curriculum resources available to them or even know where to look for those resources, could make finding enough time to prepare engineering lessons difficult to come by.

Some teachers in this study mentioned knowing so little about engineering that they did not know what they did not know. Lack of knowledge about engineering and lack of training to teach engineering were mentioned as barriers to implementing the new standards in the curriculum. These findings are consistent with the claims made by Nadelson et al. (2016). Of the current participants, 75% reported lack of knowledge as a barrier to teaching engineering. Qualitative responses related to lack of knowledge were varied, ranging from participants who felt a complete lack of knowledge related to engineering to participants who stated they knew what engineering was but they did not know how to teach it to students because they lacked the specific vocabulary and strategies needed to do so. Further, in a related article reporting on questionnaire responses from the current study sample, the researchers indicated that 85% of participants did not feel their preservice program provided them with the background knowledge and training necessary to teach engineering (Hammack & Ivey, 2017). When describing the components to include in a preservice program, participants asked for relevant hands-on training on how to use materials as well as training on where to locate available resources. One participant mentioned that many teachers have materials they could use for engineering, but because they did not receive training on how to use them, the materials sit unused, making training imperative.

More than half of participants mentioned the lack of curriculum and instructional materials for teaching engineering. Budget concerns were mentioned regularly, with participants stating that even with administrative support, they still could not gather the materials needed because their districts did not have enough funding to operate effectively. Many participants stated they have spent their own money purchasing instructional materials and have spent hours searching online for lesson ideas, both of which added stress. Multiple participants asked for a central website where they could go to locate engineering activities based on grade level and content standard and to share teacher-tested activities with one another. In addition, teachers need training to understand the types of materials that can be used to teach engineering activities and shown ways to incorporate high quality design activities in their classrooms by using inexpensive supplies such as paper, index cards, paperclips, and straws.

Another barrier that participants mentioned was lack of support at local and state levels. Participants were divided with regard to whether they felt administrative support for teaching engineering (see Figure 1). Qualitative responses included statements that the administration only supported science instruction if it was included in the reading curriculum or said administrators did not care if science was taught at all because their sole focus was on test scores. There were, however, participants who said their local administrators were supportive, but there was not much they could do because of budget cuts and mandates from OKSDE. Participants also voiced a lack of support at the state level, commenting that OKSDE puts all of these requirements in place without providing teachers with the tools and training to meet them.

Any new program, curriculum, or initiative given to teachers to enact will require training and support. However, it can be argued that requiring elementary teachers to implement an entirely new content area in which they have no professional training or experience (such as engineering) would present additional challenges than implementing a new curriculum in a subject in which they have considerably more training and experience (such as reading). Additional research related to the specific barriers of implementing new curriculum is warranted. Limited research exists on barriers to implementation that are within teachers' control (i.e., knowledge and perceptions of engineering). However, there is a dearth of literature that speaks to those barriers outside of the teachers' control (i.e., school supports for teacher PD, time for teaching science and engineering, funding, administrative supports), and additional research in these areas is needed.

6.3 | Strengths and limitations

A strength of the current study was that the sample closely mirrored the state K-5 teacher population with regard to geographic region (with the exception of Region 3), gender, teaching experience, and grade level taught. The study, however, does have limitations. First, data were limited to the members of the population who chose to participate, and because the data were self-reported, there could be response bias. Additionally, only public school teachers in Oklahoma were included in the study, potentially limiting generalizability to teachers from private schools or those employed in other states. Further, most teachers in the current study had limited experience participating in engineering-focused PD. Having an expanded set of participants who can speak to their experiences with engineering PD could allow for additional insight into the specific engineering-related PD needs of teachers.

6.4 | Conclusion and implications for practice

Overall, findings from this study indicate that elementary teachers would support the integration of engineering standards into the elementary science curriculum if they were provided with the appropriate resources, training, and support. Administrators at the local and state level need to be aware of these findings. If administrators are going to ask teachers to teach engineering standards in K-5, they must take steps to provide teachers with the tools they need to do so. This will require the development of curriculum and instructional resources and training on how to integrate engineering within already existing science lessons. Further, a website including links to quality online engineering education resources (such as TeachEngineering.org; Teach Engineering: STEM Curriculum for K-12, n.d.) needs to be maintained and marketed to teachers so that they are aware of these resources. That marketing could be overseen by a state or federal agency or educational outreach organization.

If elementary teachers are expected to teach the NGSS as written, they must be provided with the necessary funding and education to do so. At the state and national level, funding needs to be set aside for science and engineering education to develop engineering resources, provide PD, and purchase materials for classroom use. Additional funding to provide long-term support to teachers, such as follow-up trainings and professional learning communities, will also be required.

Preservice coursework in engineering education needs to be developed and offered to elementary education majors. While the current study addressed what teachers would like to see in a preservice engineering education course, further research is needed to determine the best components of such a course.

To help address the future STEM pipeline and mainline needs, the NGSS call for the integration of engineering activities into the elementary science curriculum. While many elementary teachers support the use of engineering activities in their classrooms, there are numerous barriers preventing them from doing so. To ensure that NGSS are incorporated into elementary classrooms as they were intended, elementary teachers must be provided with the necessary training, resources, and support.

REFERENCES

- Barger, M., Gilbert, R., Poth, R., & Little, R. (2006). *Essential element examples of elementary engineering in elementary education*. Paper presented at the ASEE Annual Conference & Exposition, Chicago, IL. Retrieved from <http://peer.asee.org/676>
- Berrett, J. (2006). *Engineering and technology in the elementary school*. Paper presented at the ASEE Annual Conference & Exposition, Chicago, IL. Retrieved from <https://peer.asee.org/449>
- Berry, R. Q., III, Bull, G., Browning, C., Thomas, C. D., Starkweather, K., & Aylor, J. H. (2010). Preliminary considerations regarding use of digital fabrication to incorporate engineering design principles in elementary mathematics education. *Contemporary Issues in Technology and Teacher Education*, 10(2), 167–172. Retrieved from <http://www.citejournal.org/vol10/iss2/editorial/article1.cfm>
- Blanchard, M. R., Osborne, J. W., Wallwork, C., & Harris, E. S. (2013). Progress on implementing inquiry in North Carolina: Nearly 1000 elementary, middle and high school science teacher weigh in. *Science Educator*, 22(1), 37–47. Retrieved from <https://files.eric.ed.gov/fulltext/EJ1062250.pdf>
- Broadbooks, W. J., Elmore, P. B., Pedersen, K., & Bleyer, D. R. (1981). A construct validation study of the Fennema–Sherman mathematics attitudes scales. *Educational and Psychological Measurement*, 41, 551–557. <https://doi.org/10.1177/001316448104100238>
- Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, 97(3), 369–387. <https://doi.org/10.1002/j.2168-9830.2008.tb00985.x>
- Burton, E. P., & Frazier, W. M. (2012). Voices from the front lines: Exemplary science teachers on education reform. *School Science and Mathematics*, 112(3), 179–190. <https://doi.org/10.1111/j.1949-8594.2011.00131.x>
- Cartwright, T. (2014). Confronting barriers to teaching elementary science: After-school science teaching experiences for preservice teachers. *Teacher Education & Practice*, 27(2/3), 464–487. Retrieved from <https://eric.ed.gov/?id=EJ1044960>
- Constable, H. (1994). *A study of aspects of design and technology capability at Key Stage 1 and 2*. Paper presented at Proceeding of IDATER 1994 Conference, London, England. Retrieved from <https://core.ac.uk/download/pdf/2737802.pdf>
- Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications.
- Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Los Angeles, CA: Sage Publications.
- Cunningham, C. (2009). Engineering is elementary. *The Bridge: Linking Engineering and Society*, 39(3), 11–17. Retrieved from <http://www.nae.edu/TheBridge>
- Cunningham, C. M., & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education*, 25, 197–210. <https://doi.org/10.1007/s10972-014-9380-5>
- Douglas, K. A., Rynearson, A., Yoon, S. Y., & Diefes-Dux, H. (2016). Two elementary schools' developing potential for sustainability of engineering education. *International Journal of Technology and Design Education*, 26(3), 309–334. <https://doi.org/10.1007/s10798-015-9313-4>
- English, L. D., & Mousoulides, N. G. (2011). Engineering-based modeling experiences in the elementary and middle school classroom. In M. Khine & I. Salen (Eds.), *Models and modeling in science education* (Vol. 6, pp. 173–194). Dordrecht, Netherlands: Springer.
- Fennema, E., & Sherman, J. A. (1976). Fennema–Sherman mathematics attitude scales: Instruments designed to measure attitudes towards the learning of mathematics by males and females. *Journal of Research in Mathematics Education*, 7(5), 324–326. Retrieved from <http://www.jstor.org/stable/748467>
- Fleer, M. (2000). Working technologically: Investigations into how young children design and make during technology education. *International Journal of Technology and Design Education*, 10(1), 43–59. <https://doi.org/10.1023/A:1008923410441>
- Gall, M. D., Gall, J. P., & Borg, W. R. (2003). *Educational research: An introduction* (7th ed.). Boston, MA: Allyn and Bacon.
- Hammack, R. (2016). *Elementary teachers' perceptions of engineering, engineering design, and their abilities to teach engineering: A mixed methods study* (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses Global (10188936).
- Hammack, R. (2018). *K-5 teachers' perceptions of engineering education and perceived barriers to teaching engineering*. Paper presented at the ASEE Annual Conference & Exposition, Salt Lake City, UT. Retrieved from <https://peer.asee.org/30744>
- Hammack, R., & Ivey, T. (2017). Elementary teachers' perceptions of engineering and engineering design. *Journal of Research in STEM Education*, 3(1/2), 48–68. Retrieved from http://j-stem.net/wp-content/uploads/2018/12/article_4.pdf
- Hill, A. M., & Anning, A. (2001). Primary teachers' and students' understanding of school situated design in Canada and England. *Research in Science Education*, 31(1), 117–135. <https://doi.org/10.1023/A:1012662329259>
- Hong, T., Purzer, S., & Cardella, M. (2011). A psychometric re-evaluation of the design, engineering and technology (DET) instrument. *Journal of Engineering Education*, 100(4), 800–818. <https://doi.org/10.1002/j.2168-9830.2001.tb00037.x>
- Hope, G. (2000). Beyond their capability? Drawing, designing, and the young child. *The Journal of Design and Technology Education*, 5(2), 106–114. Retrieved from <https://ojs.lboro.ac.uk/JDTE/article/view/522>
- Hotaling, L., McGrath, B., McKay, M., Shields, C., Lowes, S., Cunningham, C., ... Yao, S. (2007). *Engineering our future New Jersey*. Paper presented at the ASEE Annual Conference & Exposition, Honolulu, HI. Retrieved from <https://peer.asee.org/2231>
- Hsu, M.-C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research*, 1(2), 31–39. Retrieved from <https://docs.lib.purdue.edu/jpeer/vol1/iss2/5/>

- Lachapelle, C. P., Cunningham, C. M., Jocz, J., Kay, A. E., Phadnis, P., Wertheimer, J., & Arteaga, R. (2011). *Engineering is elementary: An evaluation of years 4 through 6 field testing*. Boston, MA: Museum of Science.
- McNamara, J. (1999). The Texas Poll of Elementary School Teachers: Part one. *International Journal of Educational Reform*, 8(2), 186–200.
- McNamara, J. (2000). The Texas Poll of Elementary School Teachers: Part two. *International Journal of Educational Reform*, 9(1), 87–99.
- McNamara, J. F., Stuessy, C. L., Parker, D., McNamara, M., Garcia, G., & Quenk, K. (1998, September). *The Texas Poll of Elementary Teachers: A chart essay on findings*. An in-conference session presented to the Texas Statewide Systemic Initiative and Texas Education Agency, Austin, TX.
- Nadelson, L., Sias, C. M., & Seifert, A. (2016). *Challenges for integrating engineering into K-12 curriculum: Indicators of K-12 teachers' propensity to adopt innovation*. Paper presented at the ASEE Annual Conference & Exposition, New Orleans, LA. Retrieved from <https://peer.asee.org/26471>
- Namey, E., Guest, G., Thairu, L., & Johnson, L. (2008). Data reduction techniques for large qualitative data sets. In G. Guest & K. M. MacQueen (Eds.), *Handbook for team-based qualitative research* (pp. 137–161). Lanham, MD: AltaMira Press.
- National Academy of Engineering and National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18612>
- National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/12635>
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13165>
- NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press.
- Oklahoma State Department of Education (2014). Reac3h Network. Retrieved from <http://ok.gov/sde/reac3h-network>
- Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and opportunities with interview transcription: Towards reflection in qualitative research. *Social Forces*, 84(2), 1273–1289. Retrieved from <http://www.jstor.org/stable/3598499>
- O'Neal, M. R., Ernest, P. S., McLean, J. E., & Templeton, S. M. (1988). *Factorial validity of the Fennema–Sherman mathematics attitude scales*. Paper presented at the annual meeting of the Mid-South Educational Research Association, Louisville, KY.
- Parsons, C., O'Hare, D., Little, R., Van Driessche, P., Parsons, K., Barger, M., & Gilbert, R. (2007). *Supporting math and science through engineering in elementary education*. Paper presented at the ASEE Annual Conference & Exposition, Milwaukee, WI. Retrieved from <https://peer.asee.org/2509>
- Pasquantonio, V. (2018, March 30). Why Oklahoma teachers are planning to walk out Monday. *PBS News Hour*. Retrieved from <https://www.pbs.org/newshour/education/why-oklahoma-teachers-will-walk-out-monday>
- Patten, M. L. (2001). *Questionnaire research: A practical guide* (2nd ed.). Los Angeles, CA: Pyrczak Publishing.
- Perrin, M. (2004). Inquiry-based pre-engineering activities for K-4 students. *Journal of STEM Education*, 5(3), 29–34. Retrieved from <https://www.jstem.org/jstem/index.php/JSTEM/article/view/1127>
- Petroski, H. (2003). Engineering: Early education. *American Scientist*, 91(3), 206–209. Retrieved from <http://www.jstor.org/stable/27858205>
- Portsmore, M. (2010). *Exploring how experience with planning impacts first grade students' planning and solutions to engineering design problems* (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses Global (3396538).
- Purzer, S., Duncan-Wiles, D., & Strobel, J. (2013). Teaching fourth and fifth graders about engineering optimization and trade-offs. *Science and Children*, 5(5), 34–39.
- Roden, C. (1999). How children's problem solving strategies develop at Key Stage 1. *The Journal of Design and Technology Education*, 4(1), 21–27. Retrieved from <https://ojs.lboro.ac.uk/JDTE/article/view/404>
- Saldana, J. (2013). *The coding manual for qualitative researchers* (2nd ed.). Thousand Oaks, CA: Sage Publications.
- Santau, A. O., & Ritter, J. K. (2013). What to teach and how to teach it: Elementary teachers' views on teaching inquiry-based, interdisciplinary science and social studies in urban settings. *The New Educator*, 9(4), 255–286. <https://doi.org/10.1080/1547688x.2013.841498>
- Schunn, C. (2009). How kids learn engineering: The cognitive science. *The Bridge: Linking Engineering and Society*, 39(3), 32–37. Retrieved from <https://www.nae.edu/File.aspx?id=16147>
- Sexton, S., Atkinson, J. H., & Goodson, R. (2013). Narratives of place: Provisional teachers' experiences in science. *Science Education International*, 24(3), 361–376. Retrieved from <https://files.eric.ed.gov/fulltext/EJ1022332.pdf>
- Teach Engineering: STEM Curriculum for K-12. (n.d.). Retrieved from <https://www.teachengineering.org/>
- Van Haneghan, J. P., Pruet, S. A., Neal-Waltman, R., & Harlan, J. M. (2015). Teacher beliefs about motivating and teaching students to carry out engineering design challenges: Some initial data. *Journal of Pre-College Engineering Education Research*, 5(2), 1–9. <https://doi.org/10.7771/2157-9288.1097>
- Wyss, V. L., Heulskamp, D., & Siebert, C. J. (2012). Increasing middle school student interest in STEM careers with videos of scientists. *International Journal of Environmental & Science Education*, 7(4), 501–522. Retrieved from <http://www.ijese.net/makale/1553>
- Yasar, S., 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*, 95(3), 205–216. <https://doi.org/10.1002/j.2168-9830.2006.tb00893.x>
- Yoon, S. Y., Dyehouse, M., Lucietto, A. M., Diefes-Dux, H. A., & Capobianco, B. M. (2014). The effects of integrated science, technology, and engineering education on elementary students' knowledge and identity development. *School Science and Mathematics*, 114(8), 380–391. <https://doi.org/10.1111/ssm.1209>

AUTHOR BIOGRAPHIES

Rebekah Hammack is an Assistant Professor of Science Education at Montana State University, 112 Reid Hall, Bozeman, MT 59717; rebekah.hammack@montana.edu.

Toni Ivey is an Associate Professor of Science Education at Oklahoma State University, 235 Willard Hall, Stillwater, OK 74078; toni.ivey@okstate.edu.

How to cite this article: Hammack R, Ivey T. Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation. *J Eng Educ*. 2019;108:503–522. <https://doi.org/10.1002/jee.20289>

APPENDIX A: List of survey questions included in the study

Barriers to Implementing DET subscale of the Design Engineering and Technology Survey:

How strong is each of the following Barriers to Integrating Design/Engineering/Technology in your classroom? (1 = not strong at all, 5 = very strong)

Lack of time for teachers to learn about Design/Engineering/Technology	1	2	3	4	5
Lack of teacher knowledge	1	2	3	4	5
Lack of training	1	2	3	4	5
Lack of administrative support	1	2	3	4	5

Modified questions from the Texas Poll of Elementary School Teachers:

Do you believe engineering is a high priority in your school?	Yes	No	Don't know
Do you believe engineering is a high priority in your school district?	Yes	No	Don't know
Do you believe engineering is a high priority for the parents in the school where you teach?	Yes	No	Don't know
Do you believe engineering is a high priority in the community where you teach?	Yes	No	Don't know
In the past 3 years, have you attended one or more professional development workshops devoted explicitly to teaching engineering in elementary schools?		Yes	No
Are you satisfied with the extent to which your school provides you with instructional materials to teach engineering?		Yes	No

What are the two most important things that would help you to improve engineering teaching in your classroom?

- ☐ More materials to teach engineering
- ☐ More support for teaching engineering
- ☐ Training and information on how to teach engineering
- ☐ Guidance in what to teach in engineering classes
- ☐ Other _____

Please elaborate on your previous response.

Assume you have been appointed to a national task force that wishes to construct a new preservice teacher methods course devoted explicitly to teaching engineering in elementary schools. What two things would you recommend they stress in developing this new preservice course?

- ☐ How to use materials to teach engineering
- ☐ How to teach engineering
- ☐ Strong background in engineering content
- ☐ More preparation prior to teaching engineering
- ☐ How to find engineering resources
- ☐ Other _____

Please elaborate on your previous response.

APPENDIX B: Individual interview protocol

1. What comes to mind when you think of an engineer?
2. Do you use engineering activities in your classroom?
 - a. If yes, please describe examples.
 - b. If no, what types of science activities do you use in your classroom?
3. Do you ever have your students design, create, or build something?
4. How would you describe your understanding of engineering?
5. What do you know about the engineering design process?
6. Do you feel prepared to teach engineering? Why or why not?
7. What sorts of things do you need to improve your abilities to teach engineering in your classroom?
8. What do administrators need to know about your needs?
9. What does the State Department of Education need to know about your needs?
10. What are your thoughts about including engineering in K-5 science standards?

APPENDIX C: Focus group protocol

1. What comes to mind when you think of an engineer?
2. Do you use engineering activities in your classroom?
 - a. If yes, please describe examples.
 - b. If no, what types of science activities do you use in your classroom?
3. Do you ever have your students design, create, or build something?
4. How would you describe your understanding of engineering?
5. Do you feel prepared to teach engineering? Why or why not?
6. What sorts of things do you need to improve your abilities to teach engineering in your classroom?