# Integrating Technology and Career Learning in Elementary Engineering Education: A Formative Curriculum Evaluation

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## Introduction

The Engineering is Everywhere ($E^2$) curriculum includes a series of video lessons led by a civil engineer who explains how he uses science, mathematics, and economics to solve practical problems. The engineer-led video lessons (a) highlight elementary grade-level applications of mathematics and science in the work of engineers and (b) introduce young students to a range of engineering careers. Co-designed with science education faculty, the $E^2$ curriculum aims to provide fun and engaging content with easy integration into formal and informal science learning (Colston, Thomas, Ley, Ivey, & Utley, 2017). An activity guide for facilitators assists in the integration of the video lessons (exploration and explanation with the engineer) with hands-on classroom activities and follow-up challenge activities (engagement and elaboration with a teacher or facilitator). The instructional videos, materials list, and activity guide can be found at: http://www.engineeringiseverywhere.com/.

$E^2$ video lessons and hands-on activities aim to increase interest and excitement about engineering careers. Pilot testing of the $E^2$ curriculum in area schools demonstrated significant gains in 5th grade students' understanding about the (a) work of an engineer, (b) the human-designed world, and (c) overall engineering career attitudes (Colston et al., 2017). Additionally, $E^2$ training workshops had positive effects on preservice elementary teachers teaching engineering self-efficacy and understanding of the work of an engineer (Ivey, Thomas, Colston, Ley, & Utley, 2014). This companion article synthesizes the findings from a formative evaluation of the $E^2$ curriculum following implementation in 5th grade classrooms. Participant teachers attended a training workshop, implemented the curriculum, and then reported about the lesson implementation, student engagement, and personal experience. The results inform decision-making about the design and development of future elementary engineering outreach efforts.

## Background

Engineering is Everywhere ($E^2$) aims to provide an age appropriate, career mentoring model that encourages and broadens participation of future students in STEM education and the engineering workforce. Identifying a trend toward decreasing interest in engineering by high school graduates (Jeffers, Safferman, & Safferman, 2004), $E^2$ addresses two unique challenges to

college and career readiness for Oklahoma public schools. First, students develop their interests, in advanced mathematics and science and attitudes about STEM careers, as early as middle school (Snell & Snell, 1992; Singh, Granville, & Dika, 2002). Early identification of STEM field interest is important to individual pursuits and long term pursuits in STEM careers (Maltese, Melki, & Wiebke, 2014). Second, the state of Oklahoma Academic Standards for Science (OASS), modeled after the Next Generation Science Standards (NGSS), have recently changed to include engineering practices in learning progressions across kindergarten to twelfth grade (K-12) science education. As it is, many elementary teachers are underprepared in STEM areas and will need new resources to help them integrate engineering practices into classroom instruction (Hammack, 2016; Ivey, Colston, Thomas, & Utley, 2016).

The $E^2$ lessons include video instruction by a working engineer that is expected to positively impact students' attention, recall, and learning (Wang & Antonenko, 2017). Increasingly, on-line videos available on websites like Secret Life of Scientists and Engineers (http://www.pbs.org/wgbh/nova/blogs/secretlife/), Engineer Girl (http://engineergirl.org/), and Design Squad Nation (http://pbskids.org/designsquad/) feature real engineers communicating about their work. While there is often contention about the value of electronic media for student learning, "the empirical evidence suggests that electronic media are no different from any other teaching tool—good for some things, and bad for others" (Schmidt & Vandewater, 2008, 77). The challenge is to determine what works, for whom, and when.

In addition to engineer-led video instruction, $E^2$ lessons activities included hand-held microscopes for student investigations of microstructures. The featured engineer (a civil engineer) uses new experimental techniques to investigate the microstructure and elemental makeup of industrial byproducts for construction applications. To support this microstructures theme, the $E^2$ videos include discussion on how microstructures influence the work of engineers. The classroom kits used in the pilot study provided hand-held, digital microscopes to support student explorations. Elementary students traditionally explore microstructures in the context of cell biology. For this grade-level, the introduction of microscopy in the context of civil and structural engineering is a novel approach.

The introduction of technology (i.e., engineer-led videos and hand-held microscopes) and career learning are expected to complement elementary students' learning about applications of science and mathematics to the work of engineers (Dyer, Reed and Berry 2006). In general, elementary engineering education focuses on design-based teaching (Brophy, Klein, Portsmore & Rogers, 2008) and may neglect to make explicit connections to science and mathematics concepts. Dankenbring and Capobianco (2015) urged the need for engineering instruction to attend to common science misconceptions by including strategies for ". . . how best to implement design-based science lessons that facilitate students' application and understanding of related science concepts"(pg. 1). The $E^2$ curriculum uses real-world examples to make specific connections between scientific inquiry, mathematical reasoning, and engineering practices (Katehi, Pearson, & Feder, 2009).

## Design, Methods, and Measures

Formative evaluation of educational curriculum using electronic technologies should include assessments of feasibility, effectiveness, and value that can inform curriculum development and revision. Our pilot study included two types of formative evaluation to inform the development of the $E^2$ curriculum (Flagg, 2013). First, pre-production formative evaluation included gathering target audience feedback prior to video production. 5th grade students at a local elementary school participated in afterschool instruction using the $E^2$ lessons and activities. Students provided qualitative feedback following each session. Specifically, students were provided with index cards at the end of each lesson and asked to respond to open-ended 3-2-1 prompts: (a) 3 things you learned, (b) 2 questions you have, and (c) 1 thing you would like to learn more about. The responses provided information about student learning outcomes, interests, and misconceptions that informed the design and story-boarding of the video lessons.

Second, implementation formative evaluation included testing the effectiveness of educational technologies in their normal use conditions (Flagg, 2013). In this study, participating 5th grade teachers completed a day-long curriculum workshop prior to implementing the $E^2$ video lessons and activities in their classrooms. During classroom implementation, the engineer instructor physically visited two of the four participating teachers' classrooms (Colston et al., 2017). Following implementation of all lessons in their classrooms, the participating teachers agreed to complete an exit survey via Qualtrics. The survey included 25-items organized into 3 thematic question types: time and arrangements, student engagement, and teacher experience (see Appendix A).

This article reports the findings from the teachers' exit survey responses following classroom implementation of the $E^2$ video lessons and activities. Using a grounded theory approach, the open-ended responses were compiled into the question categories and relevant themes were devised. Structural coding aided a thematic analysis of responses (Guest, MacQueen, & Namey, 2011) using the following text segmentations: teacher preparation, educational technologies, and student learning outcomes. Teacher responses have been anonymized and replaced with a numeric identification code. Rather than provide broadly generalizable conclusions, our findings are useful within the decision-making contexts of curriculum design and development (Flagg, 2013).

## Findings

Following a teacher workshop and classroom implementation of the $E^2$ curriculum, we administered an exit survey to participating teachers (n=4). This section summarizes the findings. First, teacher reflections support the efficacy of the teacher workshop and curriculum guide and provided tips for lesson administration. Next, teachers report positively about the use and implementation of classroom technology (video instruction and microscopes). Finally,

teachers' observations provide concrete examples of how their students changed their understanding about the applications of mathematics and science to the work of an engineer.

**Teacher preparation.** Teacher comments suggest the training workshop was helpful for guiding student learning during curriculum implementation. As one teacher explained, "It helped prepare me for some of the questions and problems they might encounter because I had some of the same questions myself (T2)." Teacher comments reflected their appreciation for being included as experts in the curriculum design process [e.g. "The openness of the committee to our input and questions was also very much appreciated (T3)"]. Teachers' described the classroom implementation of three $E^2$ lessons and offered tips for administering the student activities (Table 1). When asked about improvements to the curriculum guide, one teacher appreciated that "the additional activity materials were provided, but not necessarily required to participate (T1)." All of the participating teachers responded affirmatively when asked about their interest and plans to use the activities in their classroom again.

**Table 1.** Descriptions of $E^2$ lesson activities and teacher tips for implementation

| **Lesson title and activities** | **Teacher tips for implementation** |
|---|---|
| Intro to Engineering:<br>Students engage in reverse engineering a pen and then explore engineered objects during a scavenger hunt | • Take apart the pen on a blank piece of paper<br>• Draw and label each 'piece' of the deconstructed pen<br>• Ask students to help classmates who may have trouble getting their pens apart<br>• Use science journals and discussion prompts to record information during the scavenger hunt |
| Structural Engineering & Mathematics:<br>Students engage in block tower building challenges to explore concepts of slope and imperfections in building materials | • Ask students to work with a partner to improve on their original design<br>• Remind students to wait for activity instructions and be careful not to disturb their neighbors' towers<br>• Encourage students to look around the room at different techniques used by others |
| Materials Engineering & Science:<br>Students engage in hand-held microscope training and explore the properties of a variety of materials | • Project the microscope for group observation and discussion<br>• Pass around each item when introduced during the video lesson<br>• Allow students to find objects to explore and share with the class |

The teachers themselves developed a new individual awareness about the variety of engineers and the pervasiveness of the field in their everyday world. As one teacher reflected, "I find myself looking at objects and picturing different engineers who were involved in the design and creation of it (T1)." While the teachers recognized that engineers used science, most were not immediately aware of its integral importance to engineering design. One insightful comment captured the magnitude of this realization: "I have always thought of engineering as part of the science field. Maybe I should think of science as part of the engineering field (T4)". When asked about participating in similar activities again, one teacher agreed and commented: "I don't feel like students are given the opportunities to see what careers are available to them in a small community like ours (T2)."

Teachers also shared new personal knowledge about the everyday applications of mathematics and science in the work of structural engineers: "I hadn't ever really thought about slope affecting building materials and design. I just figured everything would be cut perfectly straight (T3)." Reflecting on the integration of science, mathematics, and engineering instruction, one teacher recognized a new range of math applications, "I realize that math is not all about calculation; so much of it is made up of record-keeping, prediction, estimation, and data as well. I feel that when I was teaching math I may not have spent enough time on data collection and measurement (T1)."

**Educational technologies**. Teacher respondents provided feedback about the feasibility, effectiveness, and value of introducing hand-held microscopes and engineer-led video instruction. First, student investigations with the hand-held microscopes provided an engaging learning context. Several teachers found that students enjoy using the hand-held microscopes for investigations: "They were completely engaged and excited about what they were able to see (T3)." Planning more instruction time for student discovery activities was a common concern. As one teacher reflected, "They could have easily spent 3 or 4 lesson periods just exploring the make-up of different materials (T4)." Second, the engineer-led videos offered a context for understanding the work of an engineer in new ways. Surprised by student enthusiasm over deconstructing and assembling a pen, one teacher remarked, "After seeing only one video, they immediately started looking at how things work quite differently (T3)." As one teacher remarked, "The lessons were great at sparking an interest in my students about the field of engineering which isn't in any science textbook (T2)."

Teachers were asked to provide examples of student reactions to the engineer-led videos. Two of the four participating classrooms experienced a visit with the engineer, which increased their interested in the videos: "They were already introduced to the engineer in person, so they felt like someone they knew was back in the classroom (T1)." Similarly, the other teacher remarked, "I think that it helped them be more engaged in the videos after they had met the engineer. They were excited to see him again (T2)." The visit with the engineer also influenced student perceptions about engineers: "They were sure he was going to be an old man with a

beard so they were shocked when he walked in the door and commented later that they didn't really think engineers looked like regular dads (T1)."

Even when the engineer did not visit the classroom, teachers observed that students were engaged with the videos: "He spoke directly to them, it made them feel like he was in the room or video-chatting live with him (T4)." Teachers suggested that a "meeting with the engineer might have changed the learning experience just because the students may have asked him different questions than they asked me (T3)." When asked about how to improve student interest and engagement, one teacher similarly commented, "I would appreciate some method of feedback that would allow the students to have the ability to either ask or make statements about their learning back to the engineer. . .they were constantly asking if they could write him a letter or email him a question (T1)." Teachers' included some examples of student questions related to engineering careers and processes (see Table 2).

**Table 2.** Sample of student questions for the engineer

| |
|---|
| How did he decide to be an engineer? |
| Why don't other teachers talk about engineering? |
| Does he know any girl engineers? |
| How much putty do you think should be used to build the best block tower? |
| How do you remember how to do all the math and science you use? |
| Can you make anything out of concrete? |

**Student outcomes.** Open-ended responses from the teacher exit survey provided examples of students' increased awareness of the applications of science and mathematics to the work of an engineer. When asked about their students' awareness about engineering, all of the teachers commented on the value of learning that there are many types of engineers and that engineers work in collaborative groups. One teacher explained, "It was great for sparking interest in my students and getting them thinking about engineering in even the smallest of everyday items (T3)." Another teacher explained that by the end of instruction, "they were able to make connections between their everyday world and the type of engineer who might be involved in doing something similar (T1)."

When asked about their students' awareness of engineers' use science, teacher responses indicated that the curriculum was valuable to introducing the process of science in a $5^{th}$ grade classroom. One teacher used the lessons to introduce the scientific method and guide students in developing a science notebook to be used throughout the year (T2). Another teacher reflected on the value of the activities at the beginning of the school year: "I didn't have a relationship built with my students yet, and these open-ended activities allowed me to see them work independently and together. They now view the activities of observing, predicting, recording, and discussing as part of science (T1)." One teacher asked her students to draw science pictures prior to the $E^2$ lesson implementation, she shared evidence of a dramatic change in understanding

about science: “Before I got a lot of drawing of bottles with different colored liquids, volcanos, and tornados. Now my students are making comments about how engineers use science to make Fritos.” (T3)

When asked about their students’ awareness of engineers’ use of mathematics, teachers cited their students’ ability to identify applications related to the concepts of measurement, weight, and slope. Applications of economics also provided an avenue for mathematical reasoning: “We talked about the importance of math to engineers given how much money is involved in designing structures and how the owner would feel if the engineer didn’t know his math (T3).” One teacher provided a specific example to illustrate how student learning directly related to the work of the engineer, “With discussion about the use of measurement, students identified the ‘best’ recipe for concrete (T4).”

## Conclusions

Conceptualized as a STEM recruitment and precollege preparation model, the Engineering is Everywhere ($E^2$) curriculum engages students in early learning about engineering careers and the applications of science and mathematics in the work of engineer. Video lessons by a working engineer and a curriculum guide for teachers aims to encourage student explorations of engineering in their everyday lives. Our pilot study included a teacher training workshop followed by curriculum implementation in $5^{th}$ grade classrooms. Teacher feedback confirms an effective application of educational technologies (videos and microscopes) and provided helpful suggestions for classroom implementation. Concrete examples of new learning about engineering careers and applications of mathematics and science indicates age-appropriate content and learning outcomes.

Formative evaluation assessments of the feasibility, effectiveness, and value of educational technologies can help to inform future curriculum development and lesson revisions. Teacher workshops and curriculum guides can support the integration of technology and career learning into classroom science instruction. Encounters with working engineers, whether by video or in-person, provide the expertise and real world context necessary for raising engineering career awareness in students and teachers. Overall, this pilot study supports conclusions that video instruction can be beneficial and time effective ways for engineers to communicate their work for broader impacts in elementary school settings (Colston et al., 2017; Laursen & Brickley, 2011).

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**Appendix A.** Teacher Exit Survey

**Time and Arrangements**

1) Please describe the implementation of the each of the lessons and activities:
   Approximately, how much time did you spend on this lesson?
   Did you break the lesson and activities into more than one class session? If so, please provide details.
   How did you introduce the lesson to the students?
   How did you implement and manage the hands-on activities for this lesson?
   Please provide any additional details about implementation.
2) Did you implement any of the suggested extension activities or design your own? If so, please describe the additional activities.
3) Considering the time required for these lessons, would you be interested in using activities like these again? (Yes, Maybe, No)
   Why or Why not?
4) Considering the content of these lessons, would you be interested in using activities like these again? (Yes, Maybe, No)
   Why or Why not?
5) Please add any additional considerations (format, management, school context, curriculum considerations, personal preferences, etc.) that might influence your decision to use materials like the Engineering is Everywhere curriculum in future classes.

**Student Engagement**

1) Based on your experience, which activities most appealed to the students? What activities were most engaging?
2) How might we adapt the E2 activities to increase student interest and engagement?
3) How did the students engage with the videos? Provide examples of students' reactions.
4) In your opinion, how might the E2 videos be improved?
5) What new awareness do your students have about engineering?
6) What new awareness do your students have about how engineers use science?
7) What new awareness do your students have about how engineers use math?
8) What new awareness do your students have about engineering careers?
9) Did the engineer visit your classroom in person? (Yes, No)

(If No)

You were able to meet the engineer at the teacher training workshop. Do you think a personal visit to your class would have changed the students learning experience?
Why or why not?

(If Yes)

How did your students respond to the engineers classroom visit?

Do you think the visit from the engineer was valuable to student engagement in future lessons? Why or why not?

10) What questions, if any, do you and your students have for the engineer?

**Teacher Experience**

1) In what way(s) did you find the Curriculum Guide to be helpful? How might we improve the Curriculum Guide?
2) In what way(s) did you find the teacher training workshop helpful? How might the training workshop be improved in the future?
3) How well did you anticipate your students' response to the activities? Did the students surprise you in any way?
4) What new awareness do you have about engineering?
5) What new awareness do you have about how engineers use math?
6) What new awareness do you have about how engineers use science?
7) What new awareness do you have about engineering careers?
8) Now that you have completed the E2 curriculum in your classroom, will you use it again with future classes? (Yes, Maybe, No)

   Why or Why not?