

Creating a Foundation for Engineering Education in Five K-12 Rural School Districts

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ABSTRACT

This paper describes the first phase of multi-year university lead partnership with rural school districts. A professional development model was designed to provide teachers in these rural schools access to professional development focused in the area of engineering design at the K-5 level. The project evaluation utilized a quasi-experimental approach to follow a cohort of twenty-six teachers and twenty-five comparison group teachers. Overall, the data suggest the project has been successful thus far in achieving the goal of increasing rural K-12 teachers' understanding of engineering design and technology concepts. In relation to the second goal related to vertical integration of engineering design and technology in the curriculum across K-12 grade levels, there is evidence of changed teaching practices of project teachers. In addition, survey data indicate teachers feel a foundation for vertical integration is in place. In relation to the last goal, teachers felt the professional development activities had increased teacher support, collaboration, and collegiality related to science instruction. However, at this point in the project there is no evidence that collaborative activities in relation to science at the building-level had increased. The paper ends with several conclusions.

Keywords: STEM, Conference Proceedings, Partnering, K-12 Outreach

INTRODUCTION

The Math and Science Leadership Initiative 3 – Rural (MASLI3-R) is a partnership between five rural school districts, Southern Illinois University Edwardsville (SIUE), and a regional office of education (see Table 1).

Table 1: District Demographics

District	R1 (Lead)	R2	R3	R4	R5
Enrollment (# Students K-12)	630	519	488	558	2794
Classification*	Rural: Distant	Rural: Distant	Rural: Remote	Rural: Distant	Town: Distant
Size	Medium	Small	Small	Medium	Large
% Low Income	33 %	44 %	31 %	39 %	42 %
Meet AYP	No	No	No	No	No

*based on National Center for Education Statistics (NCES') urban-centric locale categories (NCES, 2013). All other data was taken from 2010 Illinois Interactive Report Card (Northern Illinois University, 2010).

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It was initiated when the superintendent of the lead rural district identified the need for engineering design and technology related concepts to be integrated into the district's curriculum. Specifically, the project goals included:

1. Increasing rural K-12 teachers' understanding of engineering design and technology concepts,
2. The vertical integration of engineering design and technology in the curriculum across K-12 grade levels, and
3. Increasing teacher support, collaboration, and collegiality related to science instruction.

In order to achieve these goals, professional development was provided by School of Engineering, School of Education and SIUE STEM (Science, Technology, Engineering, and Mathematics) Center faculty to teachers over two summers starting with the elementary grades in 2011 and the middle and high school in 2012. In the fall of each year, teachers implemented engineering design related curriculum. This paper reports the activities and finding from the elementary portion of project (summer and fall of 2011).

LITERATURE REVIEW OR BACKGROUND

Engineering design and technology related concepts have been an important part of standards based science education reform since the release of the first set of national standards (1996, NRC). More recently, their importance in science education reform has become even more elevated when *The Framework for K-12 Science Education* (Committee on Conceptual Framework for New Science Education Standards, 2012) included Engineering and Technology as one four core disciplinary ideas. Increasingly, states and school districts are adding technology and engineering education as part of their efforts to improve STEM education (National Academy of Engineering and the National Research Council, 2009). An important curriculum featured in this project was Engineering is Elementary (EiE) (Museum of Science, Boston, 2011). It features a five step engineering design process: ask, imagine, plan, create, and improve (Cunningham, 2009). This model was used with the teachers throughout the summer institute with one addition, *reflect*. Whether successful in meeting the end goal or not, after attempting each project teachers were asked to consider what it was about their effort that was successful and what was not, what could be reused in future tasks and what should be changed.

Two key professional development strategies influenced the design of this project: the use of immersion experiences and the formation of professional learning communities. The engineering design immersion experiences were modeled after the immersion in inquiry science strategy described by Loucks-Horsley et al., (2003). The key element in this model is the in-depth learning of science content as teachers carry out all aspects of a scientific investigation including such things as generating a question, planning and conducting the inquiry, organizing data, etc. The goal is to engage teachers in learning that reflects what they are expected to practice in their classrooms.

One outcome reported concerning these types of professional development experiences is that teachers gain a deeper understanding of the nature of science and the need to facilitate sense making during science instruction. There were two key differences between the immersion experiences described by Loucks-Horsley et al., (2003) and the ones used in this project. First, the focus was on engineering design, not science inquiry. Second, the project supplemented the immersion experiences with field trips to visit STEM professionals.

The second strategy implemented into the design of this project was the establishment professional learning communities (PLC's). In defining what is meant by a PLC, project

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leadership defaulted to the conclusions of Fulton, F., Doerr, H. & Britton, T. (2010) in their knowledge synthesis on STEM PLC's. "Nonetheless, we maintain that it is important for the field that each of the components in the term "Professional Learning Community" should be fulfilled in order to regard some activity as a PLC: *professional* – engaging educators in the development of their professional practice; *learning* – focused on both the learning of the educators and the learning of their students; and *community* – which requires common vision, goals, purpose, and a shared sense of trust as well as collaborative work" (p. 6).

Availability of resources and the rural geographic location of the schools did not allow project leaders to provide for a high degree of site-based support during implementation. In order to ensure a level of structure and guidance for the PLC's, the Lesson Study model was adopted (Lewis & Hurd, 2011). Lesson Study is a method of teacher research that focuses on having a team of teachers develop and refine lessons to provide instruction that reflects best practices in teaching. The basic steps included (1) planning the study, (2) teaching of the lesson, (3) post lesson discussion, and (4) final reflection. It is not meant to assess an individual's teaching ability, but to investigate the instructional process and explore student understanding. This process has shown to foster a deeper understanding of content, development of quality pedagogical practices and a focus on student learning (Loucks-Horsley, et. al, 2003; Lewis & Hurd, 2011).

PROFESSIONAL DEVELOPMENT MODEL

Summer Institute

During the summer university faculty provided ten days of professional development focused at the K-5 level (see Table 2). The majority of the activities occurred on the campus of the lead rural school, which was located one hour from the university. The goal was to provide these teachers with a variety of team based design challenges. Both regular education and special education teachers were recruited and placed in teams with others from their home district. To promote communication across grade levels, each district was required to recruit at least one teacher from a higher grade range. Thus, during the K-5 institute there were a total of twenty-six teachers, but this included eight teachers from either middle or high school.

Table 2: Overview of Summer Institute Concepts and Activities

Days 1-5	Days 6-10
Engineering Concepts	Technology Concepts
<ul style="list-style-type: none">• Engineering Design• Decomposition• Simple Systems• Hierarchical Composition• Prototyping and Testing	<ul style="list-style-type: none">• Software and basic programming• Design, code, test, improve• Hardware/software systems• Creative design
Sample Teacher Activities	Sample Teacher Activities
<ul style="list-style-type: none">• Understanding systems using Duplo blocks• Prototyping using paper airplanes• Tower building using newspapers	<ul style="list-style-type: none">• Computer programming – design, test, code, improve using LEGO Mindstorm• Robotics including a LEGO robotics challenge

The first five days an engineering faculty member helped teachers more deeply understand concepts such as engineering design, simple systems, and the idea of breaking systems down into

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component parts. Teachers were teamed with others from their district and given design challenges using ordinary materials such as Duplo blocks, paper to design airplanes, and newspaper to build towers. To be successful in these activities, teachers had to utilize teamwork, critical thinking, and communication skills such as explaining and justifying their thinking. In addition, the importance of documentation was stressed and teachers were required to keep detailed design notebooks. Education faculty provided supplementary readings and participated in the debriefing sessions throughout the institute to help bridge classroom connections. The remaining days of the institute were used to introduce teachers to technology related concepts needed to build and test robots using LEGO Mindstorm material. The institute concluded with a robotics challenge. The intent with was to tie all of the workshop ideas together in one capstone experience.

The robotics challenge capstone required teams to develop a warehouse patrol robot. The robot had to dynamically determine the size of a square perimeter and then traverse a circle of the largest diameter possible within that square. The task made use of recently gained knowledge (programming a robot and using its sensors) and information that may not have been used for quite a while (fundamental geometry concepts). The participants were given a day and a half to complete the challenge and allowed to use the Internet as a resource. The task was complex enough that no teacher was able to single-handedly produce a quick solution. The teams had to make use of the engineering design process and their notebooks in order to organize information.

To facilitate classroom connections, time was allotted to explore engineering related curricular resources such as Engineering is Elementary (EiE) by Museum of Science, Boston (2013), Try Engineering by IEEE (2013), ScienceSaurus by Great Source Education Group (2005), and LEGO Mindstorms. Each teacher was provided with funds to purchase an engineering-related resource to field test during the fall.

Two days of the institute were devoted to field trips. These took the teachers out of their rural settings and allowed them to visit with STEM professionals located on and near the university partner campus. These included: a tour of the engineering labs on the university campus and presentations by engineering faculty, a tour of a lock and dam located on a major river system and discussions with professionals from the Army Corp of Engineers, and a presentation and engineering panel sponsored by the Boeing, Corp., which concluded with a tour of a museum that documents the history of the company from its involvement in the early days of aviation to modern day space travel. These interactions were intended to situate engineering and technology concepts encountered during the summer institute within the context STEM careers and real world situations.

Fall Implementation

The teacher teams established during the summer workshops were maintained throughout the fall professional development activities. Rather than solve engineering design challenges, these teams focused on curricular issues related to implementation. In this way, teachers collaborated in PLC's with those that shared a similar district context and climate. One of the primary goals of the semester was for each PLC to implement one lesson that would bring the concepts learned during the summer into the classroom. For many districts, this also provided a starting point for the integration of engineering design into the curriculum. An additional goal was to establish an implementation plan which addressed how the integration could extend beyond the life of the grant and become permanently embedded into the curriculum. Each of the districts were in very

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different places, with different administrative priorities, so implementation plans varied based on the current needs and situation of each district.

Each PLC was given instruction on the Lesson Study model. This model emphasizes teacher collaboration and student learning, but has as a focus instructional improvement. Throughout the fall semester, all participants met as a group on a monthly basis. Initial sessions focused on the lesson study process, which was outlined and explained thoroughly by two of the grant leaders. Video examples of the lesson study process were also viewed and discussed to clarify the process and expectations. In the months following, each PLC identified a research theme, developed and implemented a lesson and reflected on the process (see Table 3). One teacher from the group was chosen to teach the lesson and the remaining members observed and collected data. Videotaping was also completed by some of the groups and student artifacts were collected to provide additional information. Members of the research team visited individual schools during lesson implementation to assist and monitor the progress of the PLC's.

Table 3: Sample of Lesson Study Projects

Lesson Title/ Grade Level	Lesson Purpose
Crossing the River / Grades 2	Design and build a bridge of a certain span to hold a given weight.
Building a Bridge / Grade 3	Design and build a bridge to hold a given weight.
Simple Machines / Grade 4	Introduce technology and the function of simple machines and create a factory subsystem.
Airplanes / Grade 6	Design and build an airplane for maximum flight distance.

Each PLC reported their research lesson plans and progress to the entire group during monthly meetings. Time was also devoted to discuss team implementation plans. A great deal of latitude was provided to each district with the primary stipulations being that each plan had to promote engineering and impact students across more than one classroom. Some teams purchased the EiE curriculum with the idea they would share it across grade levels and with non-partnership teachers. Others added to this the suggestion to invite non-grant participants into their classroom to watch them model engineering lessons. These discussions were a critical component throughout the semester because ideas were exchanged, problems discussed, and innovative solutions created. This also provided teachers with a source of support and encouragement. Each could take advantage of the collective wisdom and experience of all of the teachers involved. The fall semester concluded with final presentations by each PLC to the entire group summarizing their lesson study activities and future plans to support the integration of engineering design into the curriculum.

EVALUATION DESIGN

The evaluation of the partnership goals used a quasi-experimental approach that followed the cohort of twenty-six project teachers. Twenty-five additional teachers were recruited to serve as a control group. By comparing demographic backgrounds and examining pre-test scores

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described in Table 4, it was determined they were an adequate match for the evaluation. Data from the following sources were selected to demonstrate progress toward meeting project goals.

Table 4: Data sources used to evaluate the partnership goals

Data Source	Purpose	Details of Administration
Overall Annual Teacher Survey - an external evaluator created instrument that includes prompts with a five point Likert scale stem ranging from “Strongly Disagree” to “Strongly Agree ”and open response questions.	To determine teachers perspective of the quality of the professional development	Administered to project teachers the last day of summer institute and last day of fall workshop.
Understanding Engineering Exam - multiple choice questions taken from the Engineering is Elementary Curriculum.	To determine teacher understanding of engineering concepts	Administered to both project and comparison group teachers before the summer institute activities started and after fall implementation activities were completed.
Science Teaching Efficacy Belief Instrument (STEBI) - a tool of studying teacher’s beliefs towards science and science teaching. It was developed by Riggs & Enochs, (1989).	To determine changes in teachers self-efficacy in the area of teaching science.	
Science Curriculum Survey - based loosely on the Survey of Enacted Curriculum - See Blank, Porter, Smithson (2001) The survey consists of 46 questions organized under 10 broad domains including professional collegiality, communicating scientific understanding, etc...	A discipline specific survey used to determine the types of activities that occur in the classroom, within the academic department, and in the school.	

PROJECT FINDINGS AND DISCUSSION

In the section that follows, data and discussion are organized around the three project goals.

Goal 1: Increasing rural K-12 teachers understanding of engineering design and technology concepts

In his research summary on elementary science teachers, Appleton (2007) reported limited science subject matter knowledge and low self-efficacy in science and science teaching as contributors to why many elementary teachers avoid teaching science. His summary shared research findings linking these factors to teacher behavior such as competence in questioning and the tendency to select instructional strategies that allowed teachers to maintain control of the information. Neither behavior is favorable in promoting an effective problem-based classroom.

Evidence from multiple data sources suggests both the summer institute and participation in the fall professional learning communities had a positive impact in regards to an increased content understanding. These include:

- Understanding Engineering Exam: On content tests project teachers had a 10 percentage point increase on the exam from 76% correct to 86% correct ($p = .01$). The control group teachers did not have any change, so the change in project teacher content understanding can be attributed to involvement with the project.

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- Annual Teacher Survey after summer institute: *All of the teachers “strongly agreed” that the project has increased rural K-12 teachers understanding of engineering design and technology concepts.*
- Annual Teacher Survey after fall implementation: The majority of teachers (92%) felt that the learning communities increased their understanding of engineering design and technology related concepts (75% of the teachers “strongly agreed” and 17% “Agreed.”)
- Science Teaching Efficacy Belief Survey: In relation to this goal, the survey revealed two significant ($p = < 0.01$) areas where project teachers changed opinions about their ability to teach science. The significant items included: *I know the steps necessary to teach science concepts effectively* and *I am not very effective in monitoring science experiments*. (Note that this was a reversed survey item. The average went down on this item.) The control group did not experience any changes on any items from the pre-survey to the post-survey. This suggests the changes experienced by the project teachers can be attributed to their experiences with the MASLI3-R project. When looked at together, the two items indicate greater confidence in areas that require an understanding of science.

Goal 2: The vertical integration of engineering design and technology in the curriculum across K-12 grade levels

The first step in achieving this goal was getting teachers in the project to implement engineering into their curriculum. Most, not all, of the teachers in this cycle were assigned to K-5 classrooms. In addition providing reasons why elementary teachers avoid science, Appleton (2007) summarizing reasons for limited science instruction in the elementary grades at system level. These related to such things as availability of resources, time, and perceptions related to the importance of science.

Evidence from multiple data sources suggests teacher participation in this project did help teachers integrate engineering design. In addition, it also lead to an identifiable difference in science teaching practices, and increased teachers’ self-efficacy related to the teaching of science. All of these are important steps in making progress towards this goal. The evidence is summarized below:

- Annual Teacher Survey after summer institute: The majority of teachers (96%) were confident about their ability to integrate engineering design and technology related concepts into their classroom (76% marked “strongly agree” and 20% marked “agree”).
- Science Curriculum Survey: Pre/Post analysis provided evidence of an increase in science related activities within the classrooms of project teachers. Two survey items had significantly different ratings. This included: *Teachers using more classroom time to encourage students to make guesses, predictions, or hypotheses* ($p = 0.006$) and *Integrating science with other subjects* ($p = 0.005$). Control group teachers practices did not change. In addition, when comparing frequency of practices between these two groups, a post test analysis data suggest control group teachers spend less time devoted to one item - *Do laboratory activities, investigation, or experiments in class* ($p = 0.006$). Together, these data suggest changes in project teacher’s practices due to their involvement with the project.
- Science Teaching Efficacy Belief Survey: Two significant ($p = < 0.01$) areas where project teachers changed opinions were identified. When looked at together, the two items indicate greater confidence in their ability to plan and implement effective science instruction. The significant items included: *When a student does better than usual in science, it is often because the teacher exerted a little extra effort* and *I am continually finding better ways to*

teach science. The control group did not experience any changes on any items from the pre-survey to the post-survey. This suggests the changes experienced by the project teachers can be attributed to their experiences with the MASLI3-R project.

Participation in the project did not require teachers to do more than implement one research lesson as a team during the fall. Elementary teachers in one school did struggle to find room in their curriculum, but this motivated them to start an after school science club. However, together these data provide evidence curricular materials and implementation plans developed by each team led to the implementation of engineering design by project participants. Overall, interactions with project participants revealed an eagerness to try out these new ideas.

Since this paper is a report on the first cycle of activities, it was too soon to determine the impact the project had on vertical integration. However, data indicated the large majority of teachers felt a foundation had been provided. The evidence is summarized below:

- Annual Teacher Survey after summer institute: *All* teachers felt the project had developed a foundation for vertical integration of engineering design and technology concepts in the curriculum across K-12 grade levels (72% marked “strongly agree” and 28% percent marked “agree”).
- Annual Teacher Survey after fall implementation: A large majority (94%) of teachers felt the learning communities had developed a foundation for vertical integration of engineering design and technology in the curriculum across K-12 grade levels (42% of the teachers selected “strongly agree” and 50% selected “agree”).

Goal 3: Increasing teacher support, collaboration, and collegiality related to science instruction.

As teachers engage in professional learning, Wie, et al. (2009) identified the allocation of time as a key structural support needed by teachers. In their report comparing U.S. practices to those of other nations, the authors shared that U.S. teachers spend “...about 80% of their total working time teaching students as compared to about 60% for teachers in these other nations...” (p.20). Thus, teachers in other countries have more time to plan, collaborate, and focus on the quality of their instruction. The report concluded by stating, “...the U.S. is far behind in providing public school teachers with opportunities to participate in extended learning opportunities and productive collaborative communities in which they conduct research on education-related topics, work together on issues of instruction, learn from one another...” (p. 62).

In direct contrast to this national trend, the professional development model encouraged collaboration throughout. During the summer, project teachers struggled with engineering design problems together and were able to discuss science related curricular and instructional issues across grade levels. These same teams continued working together to form PLC’s during the fall. Evaluation data indicated these activities had a positive impact in this area. Data is summarized below.

- Annual Teacher Survey after Summer Institute: *All* the teachers felt working together during the summer increased teacher support and collegiality related to science instruction (76% of the teachers selected “strongly agree” and the other 24% selected “agree”).
- The Annual Teacher Survey after fall implementation: The majority of teachers (92%) felt the learning communities had increased teacher support and collegiality related to science instruction (42% of the teachers indicated “strongly agree “and 50% indicated “agree”). With this strong support among project participants, it was possible that this would translate into changes in building level support needed to teach science. However, pre/post data from the

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Professional Collegiality section on the Science Curriculum Survey suggest no significant changes at this level have occurred.

Specifically, on this instrument project and control group teachers were asked to indicate their level of agreement with the following five prompts.

- I am supported by colleagues to try out new ideas in teaching science (4.00).
- Science teachers in this school regularly share ideas and materials (3.54).
- Science teachers in this school regularly observe each other teaching classes (2.12).
- Most science teachers in my school contribute actively to making decisions about the science curriculum (3.19).
- I have adequate time during the regular school week with my peers on science curriculum or instruction (2.04).
- Overall (2.99).

These items used a scale from 1 to 5 where 1 = “Strongly disagree”, 2 = “Disagree”, 3 = “Neutral”, 4 = “Agree”, and 5 = “Strongly agree.” Post workshop ratings for project teachers have been included. There were no significant differences among project and control group teacher responses on any of the pre or post survey items for this section. While in general, the data indicate teachers felt a sense of support to try new ideas (4.00), the project did not appear to impact the allocation of time needed to develop a collaborative learning culture in the project teachers’ schools. As evidence, the two items where teachers tended to disagree related to adequate time to work with peers on science curriculum and instruction (2.04) and regularly observing each other’s classes (2.12).

Combined with the Annual Survey Data, it appears the project has been successful in using resources to achieve this goal of increased support, collaboration and collegiality among those teachers participating in the project. In one of the partner schools this has translated to the development of a multi-grade professional learning community focused on mathematics. These teachers see a strong relationship between the goals of engineering and those of mathematical problem solving. However, for the majority of participants the environment for professional collegiality related to science instruction at the building level has not yet been impacted.

CONCLUSIONS

Even though these data are from the first phase of a multi-year project, it was possible for the project leaders to draw several conclusions from the work that has been completed. The conclusions relate to the design of the project, the integrative nature inherent in engineering based projects, and finally conclusions about the teachers.

Project Design

Delivering professional development of this nature required a team approach that made use of each partner’s expertise and resources. Like the engineering challenges introduced to the teachers, projects like these are complex with few quick solutions. No individual department on the university campus had the expertise or resources to deliver this quality of professional development by itself. The partnership required collaboration among entities on campus and a willingness to reach out to business and informal partners.

The collaborative approach utilized for professional development was successful to a point. There is evidence that it was beneficial for teachers to be involved in activities that modeled practices as they worked with other teachers across grade levels within their own districts. However, if the project would have had the resources to recruit an entire grade level or school

(Wie et al., 2009) it might have seen greater progress toward the goals related to vertical integration and increased collaboration. This would have provided a broader base of support at the school level by creating a “critical mass” for improved instruction.

In addition, Wie, et al. (2009) shared that professional development is more effective when it aligns with other reform efforts going on at the school level. This project was initiated through conversations with district level leadership. After the fall implementation activities were completed, project leadership met with district level administration to raise awareness of project results, identify concerns, and aid in recruitment of teachers for the next cycle. One outcome of this was identifying the need to get building-level principals on board with the project. In hindsight, leadership at this level should have been involved from the inception. Most of the elementary buildings were heavily involved with the adoption of the Common Core Language Arts and Mathematics and other initiatives. Teachers conveyed the idea that involvement in this project was fine as long as it didn’t interfere with their building-level initiatives.

Integrative Nature of Engineering Projects

As the summer institute unfolded, it became obvious to the teachers how easily other content area outcomes such as those associated with language arts could be accomplished using the engineering projects. Teachers were involved in verbal communication throughout the summer institute as they shared information in small group and large group settings. In relation to writing, students are required to learn and practice different forms of writing and to understand the purpose each serves. To become proficient, students need to practice these writing skills in a variety of contexts. As the design challenges became increasingly complex, the teachers’ engineering notebooks became increasingly important to the success of each team. Gilbert and Kotelman (2005) identify how notebooks such as these can be used develop forms of nonfiction writing such as descriptive, procedural, and narrative. At the elementary level, emphasizing how engineering education is a means to accomplish these alternative goals is an essential adoption strategy and may be a starting point of conversation to gain the interest of non-project teachers and building principals.

The Project Teachers

The teachers in this project embraced the engineering and technology related content and processes. As Appleton (2007) shared in his summary of research on elementary science teaching, lack of knowledge and avoidance in the area of science does not necessarily mean elementary teachers have an “anti-science” attitude. These teachers provided comments indicating how important it was for them to learn the design process and such thing as real world connections, how engineering is important in society, and the different fields open to engineering students. With the release of the Next Generation Science Standards and the pending adoption of them at the state level, teachers will have learning progressions to more clearly articulate grade level expectations. Central to these standards are the topics emphasized in this project. The results learned from this project provide insights into the nature of support needed at the elementary level.

These rural districts genuinely appreciated having an engineering program delivered to their rural setting. Teachers allowed themselves to be put into positions where they had to work with others in challenging situations—at times becoming frustrated. As the following quote from a project teacher suggests, working through these temporary setbacks when problem solving often leads to greater gain.

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“I came away from this believing that I am smart and can figure out how to do something. Just because I'm frustrated doesn't mean I'm stupid or I won't get it. I just need more time. I now know how my students must feel!”

During the entire project, they maintained a willingness to participate, take risks, and kept their enthusiasm for the project. As a result, students in these rural areas had access to engineering education in a way they would not have otherwise had.

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