An Engineering Research Program for High School Science Teachers: Year Two Changes and Results

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Abstract

The research experiences for teachers program at Central Michigan University was initiated to team in-service and pre-service teachers with undergraduate engineering students and engineering faculty, in an engineering research setting. During the six-week program, teachers learn engineering concepts and develop high-school instructional material following the new Next Generation Science Standards, so they can bring experiences back to their high school science classrooms. The program has completed its second year. This paper presents a program overview, changes made for the second year based on first year results, assessment of the teachers' experiences and understanding of engineering, and lessons learned by everyone involved.

1. Introduction

There has been much focus in recent years on the improvement of K-12 education in the science, technology, engineering and mathematics (STEM) disciplines. Studies have shown the ill-preparedness and underperforming of high school graduates in STEM, misconceptions about engineering, and the lack of proper K-12 teacher resources, education, and training (Committee on Equal Opportunities in Science and Engineering, 2000; Rivale *et al.*, 2011, Cunningham, Lachapelle, & Lindgren-Streicher, 2005). A push for better K-12 STEM education has come from government, industry, academia, and the K-12 education system alike (National Research Council, 2010). For example, the National Science Foundation (NSF) Research Experiences for Teachers (RET) program helps fund collaborations between K-12, community colleges, and universities, where the K-12 teachers can participate in engineering and computer science research, as well as training workshops, and hopefully incorporate that learning into their classrooms (National Science Foundation, 2011). In recent years, teachers participating in RET programs have been shown to have higher general STEM knowledge, motivation, excitement, and confidence (Russell & Hancock, 2007), as well as higher-performing students in the following years (Silverstein et al., 2009).

Recognizing the need to better prepare K-12 students in science, the National Research Council's Board of Science Education has recently proposed a conceptual framework for new K-12 science education standards, called the Next Generation Science Standards (NGSS), which has been adopted by many public schools across the country (National Research Council, 2012). The standards require schoolteachers to update their lesson plans, even though doing so is often significant additional work for overburdened teachers. Identifying this challenge and the opportunity available through the NSF RET program, Central Michigan University (CMU) has initiated the CMU RET program. During the six week program, in-service teachers (ISTs), pre-service teachers (PSTs), undergraduate engineering students (ESs), and engineering faculty collaborate to work on research projects, where ISTs and PSTs learn engineering concepts and develop high-school instructional material per the NGSS. Initiated in 2012, the CMU RET program has completed two years; this paper presents the program overview, assessment, lessons learned, and suggestions for colleagues interested in offering a similar program.

2. Background

2.1 Other Programs

There are many examples of similar RET and professional-development programs being run at other universities. The "E3" program at Texas A&M University exposes high school teachers to engineering research, focusing on improving teachers' awareness of engineering careers (Page *et al.*, 2013). Similar results from the physics RET program at the Georgia Institute of Technology show that teachers improved their ability to encourage high school students to pursue science or engineering degrees (Conrad, Conrad & Auerbach, 2007). A common program model is that used by Vanderbilt University's bioengineering RET program or Southwest State University's Science/Math/Technology Education Institute: summer research with lesson development for the following academic year (Klein, 2009; Klein-Gardner & Spolarich, 2011; Westerlund *et al.*, 2002). The Marine Ecology for Teachers program at Florida State University required teacher applicants to provide a videotape of an inquiry-based lesson, so as to assess what the teachers viewed as inquiry (Blanchard, Southerland, & Granger, 2008). Clemson University engaged teachers in polymer research (Benson, Medders, & Cass, 2010); Tennessee Tech University teamed an IST, PST, ES, and faculty member to work on manufacturing research (Chaote *et al.*, 2011); and the University of Dayton teamed K-12 teachers with industrial or community sponsors for team-based engineering design projects (Pinnell et al., 2012). The University of Pittsburgh RET site even helps participating teachers conduct design competitions for students the following year, with university internships given to student winners (Landis et al., 2011). Outside of RET programs, teachers can also find professional development workshops on engineering, such as those analyzed by Avery and Reeve who make several recommendations based on their findings (Avery & Reeve, 2013).

While each of these RET programs has its own merits, all of them fall short in two categories: i) limited follow-up assistance to the teachers in designing high school instructional material; ii) no demonstration of the correlation between the research projects and NGSS. Identifying these limitations, the CMU RET program has been designed with the primary goals of (Yelamarthi et al., 2013):

1. Establishing a unique collaboration between CMU faculty, various CMU education centers, high school STEM ISTs and PSTs, and an external assessment team
2. Exposing the teachers to basic engineering concepts (e.g., motion manipulation, signal transmission, energy conversion, electricity, data processing) through cutting-edge research projects
3. Facilitating the development of high school STEM instructional materials.

To do so, the program runs for six weeks during the summer, where ISTs and PSTs teachers attend workshops, group-building activities, and participate in one of six research teams. Each team consists of two teachers (preferably one IST and one PST), one undergraduate engineering student, and one engineering faculty. The CMU engineering programs are still relatively new and are currently undergraduate only.

2.2 First Year Results

For the first year of the program, 7 ISTs and 5 PSTs participated. The first week was spent on orientation: group building, program explanation, facility tours, campus logistics, and faculty research presentations. Teams were selected based on participants' input, and the remainder weeks of the program was spent with approximately (per week) 20 hours on research, 8 hours on coaching/training, 4 hours on group reflections, and 3 hours of talks and tours. The research projects were a semi-autonomous tour guide robot, an automated waste sorter, sensor development for unmanned vehicles, DC motor control, and robotic teleoperation. The coaching sessions introduced the participants to various teaching methods, hands-on learning techniques, critical thinking skills, and the NGSS. During group reflections, participants shared their experiences and take-home lessons, discussed strategies, and built group rapport. The program concluded with a public poster presentation visited by other CMU faculty, CMU administrators, and outside educators.

Program activities and outcomes continued through the following academic year. Research teams wrote, submitted, and presented conference papers. Two participants presented posters at the Michigan Science Teachers Association annual meeting. The CMU Science, Mathematics, Technology Center (SMTC) carried out continuous coaching, curricular development, and class visits. In addition, several engineering-related classroom activities were run through high school visits.

The first-year teachers, students, and *faculty rated the program as a huge success (Kaya* et al., 2013). In discussions and surveys, ISTs said that they established relationships with fellow educators, were able to participate and appreciate engineering research, and gained skills to improve their STEM-based curriculum. Likewise, PSTs said that they gained more understanding of challenged faced by ISTs as well as engineering researchers, and felt more prepared to teach and encourage engineering concepts to high school students. ES's felt that they improved engineering problem-solving and research skills, and networked with collaborators.

After the first year, the program faculty advisors met and discussed lessons learned and suggestions made for year two. Please see Yelamarthi *et al*. (2013) for full details. Summarized here, the first-year lessons include:

1. A RET program can help cultivate a research culture in an undergraduate institution.
2. RET projects must be carefully designed for a mix of backgrounds.
3. Significant preparation is needed prior to the RET weeks.
4. A RET program requires a significant time commitment from the faculty, or graduate students under the faculty.

Based on these results and lessons learned, the following changes were planned for the second year:

1. Collect personal statement of expectations from program applicants, to tailor the program and teams for everyone's goals and expectations.
2. Start preparation earlier by faculty and ESs, prior to teacher arrival, to better use the short time during the program.
3. Have teachers each write a conference paper and identify an intended conference during the program, to increase knowledge dissemination.
4. Have teachers develop and present lesson plans during the program, to improve participants coaching.

The following sections discuss the results from these changes.

3. Year 2 Program Overview

The second year of the CMU RET program was run similar to the first, incorporating the changes presented. Twelve teachers participated again (4 PST, 8 IST; 6 female, 6 male). Of the teachers, 3 PST and 6 IST were returning from the first year. The ISTs had taught a variety of subjects between 7th and 12th grade (including biology, chemistry, earth science, and physics) for a variety of years (ranging from one to eighteen). The PSTs all had a major of Integrated Science.

Based on lessons learned in the first-year, second-year program applicants were required to submit a personal statement of expectations. Sample expectation excerpts are

> "I believe this research project will be a tremendous opportunity for me to apply engineering applications to the new Science Common Core Standards. I will be able to implement these new lesson plans to my classroom."

> "With more time spent immersed in the engineering project culture, I believe I can build a better foundation in the classroom with a future centered on STEM and NGSS. I want to gain more professional development and practice turning engineering projects done in RET, into classroom activities and other classroom appropriate projects that I can use in my classroom."

Information obtained from these statements was used to update the program to better achieve program and participants' goals. For example, more time was allocated to develop lesson plans during the RET program. These lesson plans were discussed among the RET participants regarding to their alignment with the NGSS. Furthermore, participants were encouraged to document their lesson plans with the information of what specific NGSS items were addressed.

Four engineering faculty and six ESs helped lead research projects; of them, 3 faculty and 2 ESs were returning. The projects for this year were chosen by the faculty, and consisted of cell-phone application development for biomedical applications, circuit design and prototyping for digital circuits, data and image analysis for bacterial movement, numerical simulations for drug development, robotics for remote operations, and laser writer development. The teams were assigned based on teachers' expertise and preferences.

As planned for the second year, the faculty and students initiated the research projects well in advance of the teachers' arrival. For example, for one project the faculty and student purchased, built, configured, and tested hardware so it was ready to be used for an experiment as soon as the teachers began. As a result of the advance preparations, participants were more aware of the expectations and their roles in the projects. Several faculty members provided a timeline for each week, which forced participants to stay on task and work more efficiently.

In the first-year of the program, the broad range of activities limited the time left for dissemination of the knowledge gained by ISTs and PSTs. Identifying this shortcoming, the number of diverse activities was reduced to allocate more time to draft peer-reviewed conference proceedings or archival journals. As a result, ISTs and PSTs were successful in publishing seven conference papers, two journal papers, and presented their findings at numerous conferences focused on teacher education. All participants presented work at one or more conferences. Also, several coaching sessions during the second-year allowed for development of high school lesson plans including kinematics, stoichiometry, Newton's law of motion, and human digestion.

Overall, the teachers found this process to be very helpful as they were able to practice their lesson plan and get constructive feedback from their peers. The teachers also developed some material for a CMU freshman engineering course that was used by a faculty member in the following fall semester. Since the summer, CMU's SMTC helped conduct three site visits to teachers' high schools to observe and give feedback on the implemented lessons.

4. Assessment Methods and Results

Formal assessment of the second year of the CMU RET program was made in the form of

- pre- and post-program surveys of participants
- weekly in-program surveys of teachers
- post-program interviews of participants

The weekly in-program surveys were given by the program director as quick checks of how things were going. The pre- surveys and post- interviews were conducted by an external assessment office. The surveys and interviews asked both qualitative (sentence-answer) and quantitative (yes/no; rate from 1 to 5) questions. For the qualitative responses, some participants had multiple answers, thus total responses may be more than the number interviewed.

4.1 Qualitative Responses

The four faculty advisors were asked several qualitative questions before and after the program. In the pre-survey, the faculty members were asked about expectations for the program. The faculty identified the opportunity for outreach as their primary reason for participating. They admitted having little experience working with non-engineers in their labs – the only experiences being from those who had participated in the RET program the previous year. They anticipated benefits of

- Teachers thinking like engineers, working on new science standards and getting experience and ideas for K-12 classroom activities
- Faculty doing research in a team, and building relationships, and publishing results
- Engineering students having opportunities for teamwork, research, and development of professional and social skills

Meanwhile, they anticipated the primary challenge being how to balance the needs of the teachers with their own needs as a researcher.

In the post-program interviews, the faculty were asked similar questions. The faulty said that the teams worked well together, and were successful in their projects. Specific questions and responses are shown in Table 1. The benefits and challenges mentioned are similar to those from the pre-survey. In general, the faculty felt that the teams worked well, that the experience was useful for the teachers, and that the program was beneficial for the university.

Similarly, the "participants" (the PSTs, ISTs, and ESs) were asked several questions prior to the program. The participants said that they were participating for the learning or engineering experience, to become better teachers or researchers, and to network with others. The second-year teacher participants said they returned because the first year was beneficial – it was a challenging experience, it helped relate engineering to students, and it helped them learn about the NGSS. All participants said they expected to learn about engineering research and how to implement engineering in the classroom, but that they expected those to be challenges as well. All participants expected the program to benefit high school students.

During the program, the teacher participants were given weekly surveys, to assess how various aspects of the program were going. For example, a survey might ask the teachers to rank how thorough or effective a teacher's lesson plan demonstration was that week, or how useful a workshop was. Each survey asked for overall ratings of the teachers' research experience that week. The responses to these surveys were used to adjust the program schedule and events. Overwhelmingly, the teachers' responses

Question:	**What have been the major benefits for, and effects on, the various participants in the program?**
Responses:	Teachers got to see engineering Teachers got to work on new standards and curriculum. PSTs got to learn from ISTs Engineering students worked with non-engineers. Engineering students got experience on a research team. Engineering students developed leadership and communication skills Faculty's research was furthered.
Question:	**What have you learned about improving the teaching and learning of science at the high school level through your experience in the program?**
Responses:	Teachers deal with a lot. When teaching engineering, it's important for teachers to stress that there's a problem to solve.
Question:	**What is your sense of how teachers are using or will use their research in the classroom?**
Responses:	They will directly use their skills or knowledge. They will more strongly stress hands-on learning.
Question:	**What are the greatest accomplishments of the program?**
Responses:	Opportunities for the teachers. Fostering research culture. Improving research skills of engineering students. The research accomplished.

Table 1. Faculty Interview Responses (paraphrased excerpt)

were positive. The main improvement from the first year was clearer expectations and more advanced scheduling, leading to lower anxiety and increased productivity.

At the completion of the program, the six engineering students were asked questions regarding their research experience with the faculty and teachers. Responses to several questions are paraphrased in Table 2. The engineering students unanimously felt that the teams worked well together, and that the program was beneficial for them and for the teachers.

The participants (8 PSTs, 4 ISTs, and 6 ESs) were asked qualitative questions both pre- and post-program. Table 3 compares their answers to three of these questions; for space, only duplicated responses are included. Teachers said they learned about applying engineering to their classrooms, and planned on doing so; engineering students said they learned engineering and problem solving skills. All but one of the participants said the program meet their expectation.

4.2 Quantitative Responses

The program participants were also asked quantitative questions, both before and after the program.

In the post-program interview, the participants were asked to rate the program on several aspects using a 1-5 scale.

- "How well were the following program goals accomplished? (1=Not Accomplished; 5=Accomplished)."
- "How useful were the following activities? (1=Not Useful; 5=Very Useful)."

Tables 4-5 show responses with the corresponding mean and standard deviation (S.D.).

As shown in Table 4, the participants said that the program strongly achieved all but one of its goals – it fostered good relationships, developed skills and materials, was successfully implemented, and discussed "scientific" and "teacher" languages. The goal in question ("convey") was rated as not accomplished. The failure of this goal is most likely because the second-year projects strayed farther from the unifying theme of smart vehicles.

Table 5 shows that the participants varied on their view of the usefulness of different activities, although all found the social and team-building activities to be useful. The ISTs found the curriculum coaching to be the most useful, while the PSTs found lab training and professional development sessions, to be useful.

The participants were also asked about their future plans, such as conferences, papers, and graduate school (see Table 6). The second-year teams were much more productive than the first year teams in terms of research dissemination – all teams produced conference or journal publications.

Before and after the program, the teachers were asked to rate how well they were familiar with the Next Generation Science Standards (1-5 scale; 5 = very well). The ISTs rated their familiarity as 3.25 pre-program but 4.50 post-program – a statistically significant increase ($p = 0.038$). The PSTs rated their familiarity as 2.50 pre- and 3.75 post- – an increase of 1.25 ($p = 0.080$).

Finally, the teachers were asked (before and after) to

Question:	**What was your role in the project?**
Responses:	Assist or guide to the teachers. Supervisor or leader. Collaborative part of a team.
Question:	**In what specific way has your knowledge of engineering/science been enhanced by participating in the program?**
Responses:	I've learned more engineering, math and science. I've applied the principles I learned in classes. I think more about making engineering more applicable to people.
Question:	**What are the benefits, knowledge, and skills gained from participating in the program?**
Responses:	Lab/research experience and skills Programming skills Teamwork skills Learning and experience that can't be done in a classroom. Employed. Learning how teachers see/view engineering.
Question:	**What are the strengths of the program?**
Responses:	Multidisplinary teams. Teachers get exposed to engineering We are learning and teaching
Question:	**What are the limitations of the program?**
Responses:	The limited time (six weeks). The research project was challenging or frustrating

Table 2. Engineering Student Interview Responses (paraphrased excerpt)

What are one or two ways you will use what you have learned or developed through the summer program?			
Responses:	**ISTs**	**PSTs**	**ESs**
I will implement activities/lessons, or redesign activities/lessons	7	3	--
I can apply what I have learned to future projects.	--	--	2
What are one or two BIG ideas you have learned through your participation in the summer program?			
Responses:	**ISTs**	**PSTs**	**ESs**
Engineering can/should be applied to the classroom.	2	3	1
It's okay if things don't work out the first time.	2	1	1
Engineering is a process.	3	--	--
After participation in the program, did your perception of benefits to high school students change? If so, how?			
Responses:	**ISTs**	**PSTs**	**ESs**
Yes -- [Miscellaneous reasons. Most common answer: I plan on incorporating engineering into my classroom.]	6	2	3
No	2	2	3

Table 3. Participants' Qualitative Responses (paraphrased)

	IST (n=8)		PST (n=4)	
	Mean	S.D.	Mean	S.D.
Foster trusting, successful working relationships between faculty researchers, experienced engineering students, and teachers.	4.3	0.64	4.75	0.50
Develop skills abilities, and attitudes related to leadership, curriculum development, and assessment.	4.38	0.52	4.00	0.82
Facilitate the development of high school STEM-based classroom instructional materials for use in rural areas of the state.	4.25	1.39	3.75	0.50
Convey basic engineering concepts through research projects on smart vehicles.	2.50	1.60	1.50	1.00
Successfully implement a six-week summer research experience within the labs.	4.50	0.76	4.50	0.58
Recognize "scientific language" and "teacher language," and know when and how to use each language.	3.75	1.04	4.50	0.58

Table 4. Participants' Responses to "How well were the following program goalsaccomplished? (1=Not Accomplished; 5=Accomplished).

	IST (n=8)		PST (n=4)	
	Mean	S.D.	Mean	S.D.
Participating in intensive research on various aspects of smart car vehicle development.	2.13	1.13	1.25	0.50
Coaching on curriculum development with new standards.	4.25	1.04	3.75	0.50
Faculty visits highlighting research and education topics.	3.25	0.46	3.25	0.96
Training sessions for lab instruments and/or tools.	2.75	1.04	4.00	0.82
Professional development sessions on effective teaching.	3.25	1.04	4.00	0.82
Social activities and team building activities.	4.00	1.07	4.00	0.82

Table 5. Participants' Responses to "How useful were the following activities? (1=Not Useful; 5=Very Useful)."

"Yes" responses to "Are you planning to..."	ISTs (n=8)	PSTs (n=4)	ESs (n=6)	Total (n=18)
... participate in any scientific conference?	7	4	3	14 (78%)
... develop a poster or research paper of your work?	8	4	4	16 (89%)
... make any formal presentation of your work?	7	3	3	13 (72%)
... pursue graduate school?	7	3	2	12 (67%)

Table 6. Participants' Future Plans

rate how much they agreed (5) or disagreed (1) with the following ten statements about science and engineering, to judge how the program changed their impressions of science and engineering.

Science:

S1. A lot of things in science must be simply accepted as true and remembered.

S2. It is important to teach students how to think and communicate scientifically.

S3. Every student should feel science is something she/he can do.

S4. I understand *science* concepts well enough to be effective in teaching them.

S5. I am typically able to answer students' questions related to science.

Engineering:

E1. You have to study engineering for a long time before you see how useful it is.

E2. Memorization plays a central role in learning basic science and engineering concepts.

E3. Every student should feel *engineering* is something she/he can do.

E4. I understand *engineering* concepts well enough to be effective in teaching them.

E5. I am typically able to answer students' questions related to *engineering*.

Table 7 shows responses. After the program, the teachers felt better prepared to teach engineering (E4 and E5), and found that engineering was more clearly useful (E1) and less about memorization (E2).

5. Conclusion

The program changes suggested from the first year results were successfully implemented into the second year. The participants drafted statements of expectation, the project teams were better prepared and more productive, the teachers developed more (and even better) lesson plans, and the participants published at and attended many more conferences. The lessons learned by the faculty from the first year were true again. Once again, the RET program nurtured a research culture at CMU. The research projects were more carefully designed (especially ahead of the RET week) and were more successful – such preparation and execution required a large time commitment from the faculty.

Overall, faculty felt that the program offered major benefits for both the teachers and the engineering students, that teams worked together, and that the teachers will use their experience to stress more hands-on learning. They felt that the program was beneficial to CMU but also saw some frustrations in accomplishing the projects.

As a whole, the engineering students had good relationships with their faculty advisor and teacher team members. They found the weekly team meetings to be beneficial, learned specific concepts and gained valuable experience in engineering research, would recommend it to other students, but acknowledged some limitations in the program.

In general, the teachers enjoyed the experience. They learned about engineering and felt better prepared to teach it. They plan on incorporating it into their classrooms. They are also more knowledgeable about the Next Generation Science Standards. Most of the teachers are or have published conference papers or presentations on their research and/or experience, and are participating in the in-class follow-ups with CMU's SMTC.

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	In-Service Teachers (n=8)				Pre-Service Teachers (n=4)			
Question	Pre	Post	Diff	p-value	Pre	Post	Diff	p-value
S1 (accepted)	2.25	2.25	0.00	1.000	3.25	2.50	-0.75	0.215
S2 (scientifically)	4.75	5.00	0.25	0.170	4.25	4.50	0.25	0.391
S3 (can do)	4.88	4.88	0.00	1.000	5.00	4.50	-0.50	0.391
S4 (I can teach)	5.00	5.00	0.00	1.000	3.50	4.25	0.75	0.215
S5 (I can answer)	4.75	4.75	0.00	1.000	3.75	4.00	0.25	0.391
E1 (study)	1.75	1.63	-0.13	0.685	2.00	1.25	-0.75	0.058
E2 (memorization)	2.38	1.75	-0.63	0.049	2.75	2.75	0.00	1.000
E3 (can do)	4.63	4.50	-0.13	0.685	3.75	3.75	0.00	1.000
E4 (I can teach)	3.00	4.25	1.25	0.005	2.00	3.25	1.25	0.015
E5 (I can answer)	2.75	3.88	1.13	0.026	2.25	3.00	0.75	0.215

Table 7. Teachers' Perspectives on Science and Engineering.

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