A Multidisciplinary Engineering Research Program for Middle and High School STEM Teachers

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Abstract

Science, technology, engineering, and mathematics (STEM) education in K-12 schools is critical to inspire young students and prepare them for future college coursework and careers in science and engineering. An effective mechanism for creating and sustaining successful STEM education is to train well-qualified K-12 teachers with a positive attitude and deep knowledge skills in STEM fields. Supported by the National Science Foundation's Research Experience for Teachers program (NSF RET), the RET Site at Michigan State University (MSU) aims to build a multidisciplinary engineering research program for middle and high school teachers and their students, within a coherent theme of "Smart Sensors and Sensing Systems". This paper presents an introduction to the MSU's Site program and highlights the learning outcomes and achievements of the RET participants. The MSU Site has four main components including authentic research experience for teachers during an intensive summer program; curriculum development by integrating engineering design units into teachers' courses; professional skill development through seminars, facility tours, and field trips; and finally classroom implementation of the developed curricula. Throughout the 6-week summer program, teacher participants were given the opportunity to work closely with graduate students and engineering professors on current research projects in university laboratories. The teachers' research activities culminated with a final poster report and oral presentation during a symposium at the end of the summer program. Follow-up classroom visits helped to build a strong connection between local middle/high schools and MSU to smooth students' transitions to college. Since 2016, the Site has provided a total of 31 projects for 25 Michigan STEM teachers recruited from high-needs and rural schools in the State of Michigan, including Brighton, Detroit, East Lansing, Lansing, Okemos, and Perry school districts. Our RET teachers have developed 36 sets of lesson and hands-on activity based on their research experiences, of which four lessons and five hands-on activities have been published by TeachEngineering.org. To date the total TE page views of our teachers' lessons and activities are over 30,000. These curriculum materials have made significant contributions to the improvement of classroom experiences of middle and high students in Michigan and beyond. Our RET Site also helped to inspire and prepare high school students for future college studies in the STEM fields. As a result, the Computer Science major at MSU had the biggest freshmen enrollment on the record in the fall of 2018. To reach a larger audience, the RET Site disseminated the project outcomes widely through publications in journals and presentations at international and national conferences and workshops. The success and rigor of our RET Site project were reflected by the program assessment, where all the teacher participants reported high levels of satisfaction with many facets of the program.

Introduction

Workforces in science, technology, engineering, and mathematics (STEM) drive the nation's innovation and competitiveness in the 21st century by generating new ideas and technologies. Job opportunities in STEM fields are always growing faster than non-STEM occupations [1]. However, the interest of U.S. students in STEM fields has been stagnant or declining over the past two decades [2, 3], and there also is an inadequate pipeline of teachers skilled in those subjects. The National Science Foundation's NSF Research Experience for Teachers (RET) program connects research universities, community colleges, and local K-12 school districts to foster both professional development for STEM teachers in the fields of engineering and computer science and to develop local curricula to prepare students for study in engineering fields [4]. RET Site programs have historically had a strong positive impact on K-12 educators in terms of both professional development and ability to generate enthusiasm for STEM fields in their students.

Michigan State University (MSU) has enjoyed great success with several RET Site projects since 2009, which provided fertile ground to build upon and improve procedures for the RET Site discussed in this paper, "Smart Sensors and Sensing Systems" (4S) at Michigan State University. The 4S RET Site aims to achieve the goals of the RET program writ large by training these teachers in methods and applications for cutting-edge research on a wide variety of sensors: biological, chemical, microelectronic sensing circuitry, human-computer interaction, biomechanics, etc. Four components of the MSU RET Site structure the teacher training: authentic research experiences for teachers during an intensive summer program; curriculum development by integrating engineering design unites into teachers' courses; professional development through seminars, facility tours, and field trips; and classroom implementation of the developed curricula.

The objectives of the current RET site are to: establish a strong partnership between Michigan State University and school districts on advancing pre-college science and engineering education; train middle and high school STEM teachers that can develop students' confidence and skills to succeed in a competitive global marketplace; develop and implement innovative curriculum by translating cutting-edge university research into classroom practices; and lay the groundwork for a new, sustainable, industry-sponsored RET paradigm enabled by partnership between university, industry, and schools.

This paper provides an overview of the overall structure of the RET Site in question. It draws a blueprint for the recruitment of teacher participants, as well as a description of the ways in which teachers were prepared for the six-week research activities during the Site's Summer Institute. The paper also describes various professional and curricular development activities teachers participated in. Finally, the major outcomes of the RET Site and recommendations for best RET Site practice are discussed.

Methods and Site Activities

Recruitment

The RET Site targeted middle and high school teachers in STEM areas, and recruited between 10 and 12 teachers per year. Top performing teachers were invited to return to the Site the following year. Returning teachers had the opportunity to further develop their research and professional skills. Teachers did not participate in the Site for more than two years. Teachers were drawn from Brighton, Detroit, East Lansing, Lansing, Okemos, and Perry areas, as well as Math, Science, and

Technology (MST) Centers in Michigan. These schools were chosen because of their proximity to Michigan State University and their large populations of students from groups underrepresented in STEM fields. Successful applicants were matched to faculty based on matching skill sets and interest in the research project descriptions developed by faculty. For the selection of returning teachers, past RET performance--including curriculum development and implementation—and leadership skills were major criteria in the decision making process. The Site also promoted teacher participants from groups that are historically underrepresented in STEM fields, with over 50% being females and minority participants.

Solicitation of Research Projects

Each year the Site recruited 10 to 12 faculty members from different departments in the college of engineering, who have proven strong track records of sensor-related research and outreach. Over 80% of them had served as RET faculty mentors through the prior Site programs. Prior to the Summer Institute, faculty mentors provided a list of possible projects for prospective teachers. Each project had a one to two-page description of research goal, context, nature, required or desired skills, and significance of the project, written in layman's terms. Getting faculty's input each year ensures the match of RET projects with faculty's interest and research needs, fostering a win-win situation for both faculty and teachers.

Six-Week Summer Institute

The Summer Institute provided recruited teachers with a focused campus experience in authentic engineering research. An orientation program carried out during the first two days of the Institute was designed to acquaint the participants with the RET Site program and resources at MSU, and transition them quickly into research and professional development activities. The orientation involved teachers, graduate students, PI and Co-PI, the curriculum development specialist, and the program evaluator. During the orientation, all participants the third day back on the MSU campus for logistics and lab safety training.

The hallmark of the Summer Institute is the intensive research experience for teachers, who worked closely with faculty mentors and their graduate students. Teachers spent, on average, between 25 and 30 hours per week conducting lab research. The "faculty-teacher-graduate student" trilateral interaction model that has proven successful in past MSU RET Site programs. Under such a model, one faculty member is assigned to a RET participant, and a faculty member's graduate student provides daily one-on-one mentoring to the participant, as well as training in and assistance with equipment training, experiments, and research skills. Sustained one-on-one mentoring ensured that the RET teacher maintained close contact with the faculty mentor and received adequate attention and research training. Teachers were also given primary responsibility for their research projects, thus fostering the development of creativity and leadership skills.

Additionally, the 4S Site at MSU provided time and space to develop curricular materials motivated by their research experiences. Teachers were encouraged to spend at least 10 hours per week on their curricular modules, and to develop at least one module that included both a lesson plan and a related classroom activity. All related educational standards, such as the State [5-7] and/or National Standards of Learning [8-10] were integrated into the design and delivery of all RET teaching kits and materials. Teachers met with a curriculum development specialist once per week in one-on-one feedback on curriculum materials. Teachers in the same STEM area were

encouraged teleconferences to discuss ideas and provide to work in groups in order to better facilitate curriculum development. Developed curriculum modules were submitted to TeachEngineering.org (TE), an online database for K-12 curriculum dissemination.

Throughout the Institute, teachers also participated in a number of activities to broaden their horizons, build their confidence, and sharpen their leadership and communications skills in order to strengthen their capabilities as STEM educators. In particular, workshops and Brown Bag seminars were arranged every week including the orientation week, to expose the teachers to engineering disciplines and exciting advances in technology. Field trips were organized every two weeks, including tours to state-of-the-art laboratories (e.g., the National Superconducting Cyclotron Laboratory and the Fraunhofer Center for Coatings and Diamond Technologies at MSU), local companies, (e.g., GE Aviation, General Motors), as well as cutting-edge facilities of faculty mentors' labs. The teachers and graduate student mentors were also invited to showcase their summer research and curriculum demos in the Metro Detroit Youth Day, which is the largest annual youth event in Michigan and has drawn over 1 million youngsters over the years.

Follow-Up Activities

After the 6-week Summer Institute, follow-up activities were conducted throughout the subsequent academic year to evaluate the long-term impact of the RET programs on teachers and their students, and to foster and strengthen the partnership between MSU and participating school districts as well as the relationship between faculty mentors and RET participants. Faculty members and graduate students conducted school visits to give expository lectures showcasing intriguing engineering research, and interact with students and teachers on various subjects from curriculum, to university research, and to life as an engineering student, researcher, or engineer. The PIs and program evaluator visited the participating schools on a regular basis to evaluate the long-term impact of the developed curricula on students' learning experiences. Student feedback was collected, analyzed, and provided to the teachers for future improvement and implementation of the curriculum.

To evaluate the impacts of the RET Site, a comprehensive assessment of the program was conducted by an external evaluator to provide: 1) quantitative and qualitative evaluation of the Summer Institute through periodic survey, on-site observation, focus groups, and interviews; and 2) longitudinal studies on the current and prior participants by tracking their professional and leadership activities, understanding and interest in engineering concepts, and exploration of engineering topics in the classroom. Data was collected using periodic surveys, focus groups, interviews with site participants, observational visits to participating schools, and review of participant artifacts.

Major Outcomes

The RET Site at MSU hosted 25 teachers in total, with about 56% of the participants being female and minority. All the teacher participants were carefully selected from Michigan middle and high schools (**Table I**), ensuring balanced geographic representation across the state. At least two teachers were recruited from each school district, supporting the collective engagement of participants. An exception was given to teachers from economically disadvantageous and rural school districts with an emphasis on a need for increasing the availability of quality professional development opportunities in such areas.

Table I: Geographic representation of the teacher participants

# of Teachers	Schools	School district
1	Brighton High School	Brighton
2	Renaissance High School	Detriot
2	Detroit Edison PSA	Detriot
1	Gross Point High School	Detriot
2	East Lansing High School	East Lansing
1	McDonald Middle School	East Lansing
1	Kosciuszko Middle School	Hamtramck
1	Haslett High/ Middle School	Haslett
4	Sexton High School	Lansing
1	Waverly High School	Lansing
1	Everett High School	Lansing
1	LCC/East English Village Prep Academy	Lansing
3	Okemos High School	Okemos
2	Perry Middle School	Perry
1	Pontiac High School	Pontiac
1	Macomb Math and Science	Warren

The teacher participants successfully obtained meaningful and authentic research experience in multidisciplinary fields of computer science and engineering, electrical engineering, mechanical engineering, as well as bioscience and technology. Additionally, the professional development activities have trained teachers in conceptual understanding, curriculum development, critical thinking, leadership, and communication skills, as reflected by the publication of high-quality lesson plans and classroom activities. By January 2019, 36 sets of standards-compliant curricular modules have been produced by our RET teachers, of which four lessons and five hands-on activities have been published. Examples of published lesson plans and classroom activities are: "Keeping Our Roads Smooth" by Adam Alster [11]; "Scaling, Go Figure!" by Evelynne Pyne [12]; and "Exploring Nondestructive Evaluation Methods" by Marianne Livezey [13].

Additionally, the outcomes of our RET Site were disseminated at the College of Engineering Design Day Teachers Workshop and national conferences. Participants of the workshop include teachers and school officials from Mid- and Southeast Michigan, outreach personnel from other universities, as well as representatives from local companies. The workshop offered a forum for universities, industry, and school districts to discuss collaboration plans on teacher training and more generally, on STEM education. It also provided a great opportunity to attract potential RET participants.

Evaluation and Discussion

In the last two years of the RET Site, the outcomes were largely positive. Assessments were made in five key categories of the program: preparation for the Summer Institute, research, curriculum development, professional development, and continued involvement. Online surveys were conducted and summarized in **Table II**, the surveys yield strongly positive results regarding the overall program participation, indicating the great success of our RET Site programs. Teachers responded that the program had prepared them to create more innovative lesson plans motivated by their research, that the professional development opportunities provided by the RET Site had

Table II: RET Post-Program Survey Results

Categories	*Completely satisfied & satisfied (%)*	
	New participants	**Returning participants**
Please rate your overall satisfaction with the RET program	100	100
Please rate the mentoring provided by the faculty mentors	87.5	100
Please rate the mentoring provided by the graduate students	87.5	100
Please rate your satisfaction with working with the consultant from teachengineering.org on curriculum development	100	100
Please rate your satisfaction with the professional development opportunities offered through the RET program	100	100

been beneficial, and that the experience had overall been worth the somewhat heavy investment of time and effort made by them.

Additionally, open field comments in the surveys allow participants to provide more detailed feedback regarding program highlights and areas for improvements. Examples of positive verbatim statements from the qualitative survey items include: "A better understanding of the engineering design process and how it differs from inquiry instruction"; "This program immensely helped me create an innovative curriculum that incorporates engineering design"; "I feel as if I am a better teacher because of this program"; "the graduate student was there often and answered any questions I may have had. He was very helpful and supportive".

Curriculum development is always a topic that was discussed extensively in the evaluation reports. Although the overall satisfaction level for the curriculum development element was high, major challenges remain including limited time for curriculum development and process of submission to TeachEngineering.org. "Master Teacher" was created in response to these challenges and has become a positive addition to the program. The Site will continue this successful model by leveraging the education expertise of a curriculum development specialist and the positive role model of the master teacher. Another positive lesson learned is the orientation events for teachers, faculty and graduate student mentors before the Summer Institute, through which they got a better understanding of the RET program, their responsibilities, and expectations on their involvement. The Site will continue to arrange orientation and social events for faculty and teachers, providing opportunities for interaction and collaboration not only at the orientation but throughout the whole program. This will help enhance the outcomes of the RET Site and build a much stronger connection between the teachers and their faculty/graduate student mentors. Finally, while the program evaluation based on periodic online surveys perfectly served the purpose of improving the Site operation, it did not reflect the long-term impact of the RET experience on participants' career paths. In the further, we will collaborate with the evaluator to conduct on-site interviews and longitudinal studies on the current and prior participants by tracking their professional and leadership activities.

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References:

[1] GAO, "Science, Technology, Engineering, and Mathematics Trends and the Role of Federal Programs, statement of Cornelia M. Ashby, Director, Education, Workforce, and Income Security Issues.," *Accessible at http://www.gao.gov/new.items/d06702t.pdf*, 2006.

[2] N. S. Board, "Science and engineering indicators 2004," ed: NSB Publication No. NSB, 2004.

[3] "Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, Committee on Science, Engineering, and Public Policy, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*," ed: Washington, DC: National Academy of Sciences, 2007.

[4] (January 30, 2019). *Research Experiences for Teachers (RET) in Engineering and Computer Science*.

[5] "Educational Technology Standards and Expectations for Grades 9 - 12," Michigan Department of Education, http://www.michigan.gov/documents/9-12_150927_7.pdf.

[6] "Educational Technology Standards and Expectations for Grades 6 - 8," Michigan Department of Education, http://www.michigan.gov/documents/METS_6-8_129586_7.pdf?20151018170817.

[7] "Michigan's high school science content expectations," https://www.michigan.gov/documents/mde/Essential_Science_204486_7.pdf.

[8] "National Committee on Science Education Standards and Assessment, National Research Council, National Science Education Standards," *Washington, DC: National Academy of Sciences*, 1996.

[9] "National educational technology standards for students 2007," International Society for Technology in Education, Available at http://www.iste.org/standards/nets-for-students/nets-student-standards-2007.

[10] "Standards for technological literacy," International Technology and Engineering Educators Association, Available at http://www.iteea.org/TAA/PDFs/xstnd.pdf.

[11] A. Alster, "Keeping Our Roads Smooth," *TeachEngineering*, 2016.

[12] E. Pyne. Lesson: Scaling, Go Figure! [Online]. Available: https://www.teachengineering.org/lessons/view/mis_scaling_lesson01

[13] M. Livezey. Lesson: Exploring Nondestructive Evaluation Methods [Online]. Available: https://www.teachengineering.org/lessons/view/mis-1616-nondestructive-evaluation-systems-equations-fem