

A Nine Year Study of the Impact of Middle and High School Teachers' Participation in Research Experiences for Teachers Programs: Connections Between Teacher Performance and Student Achievement

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Abstract

Research identifies a national urgency to improve teacher performance and student achievement in science and engineering. This paper responds to this need and presents the results of nine years of Research Experience for Teachers (RET) programs funded by the National Science Foundation, in which engineering faculty collaborate with middle and high school teachers and their students. One program (4 years) is a comprehensive teacher professional development program in which middle school teachers participate in an intensive summer research experience in computer science and engineering labs, build curriculum based on the laboratory research content that they learn, participate in lesson study, and implement new curriculum in their middle classrooms. The second program (5 years) is a high school teacher RET program with similar components. This paper contains a combined report of results of both of the RET programs. The two programs had the combined intent of bringing innovative computer science and engineering research to middle and high school teachers and their students and improving teacher performance, while simultaneously improving student achievement through scientific inquiry, engaging students in computational thinking, and engineering design. The programs' design included a summer intensive experience in which teachers fully participated in a computer science or engineering laboratory research and engaged in an inquiry focused content-to-pedagogy teacher professional development workshop, building curriculum from their lab research experience with foci on scientific experimentation and improving students' STEM achievement and content area literacy. The programs were both aligned with Common Core Math Standards and Next Generation Science Standards and addressed the research question: What is the impact of an intensive research-based teacher professional development program on both teacher and student performance?

In total, eighty-seven teachers and their 12,436 students participated in the two RET programs combined. Assessment measures used to determine the impact of the two RET programs were: a teacher instructional performance measure, the Science Teaching Efficacy Beliefs Instrument-revised, a STEM content area qualitative reading inventory, grade and content specific concept inventories, and a student motivation for science questionnaire. The combined program results were the highly impactful. The RET teachers had a mean science teaching efficacy significantly higher than the national average. The mean score on teacher performance measure was also significantly higher than the state's average rating. The RET teachers also had a significant performance gain pre-to-post program. Student related results indicated gains as well. Specifically, the participating teachers' students made significant gains during their curricular intervention resulting from their teachers' participation in the RET programs. The students gained computer science and engineering knowledge, increased their science interest and motivation, and demonstrated gains in STEM literacy as well. These results indicate that research experience for teachers programs benefit both the teachers and the students that they teach.

Introduction and program need

[Portions of this paper in the review of the literature and research design have been reprinted from the 2016 and 2017 ASEE NSF Awardee Poster Session Papers, which provide preliminary material for the reader.]¹

There is a growing national concern over decreases in science achievement in middle and high school. Paired with it are challenges associated with workforce declines in STEM-related careers. In response, in a recent PCAST report,² recommendations for recruitment of science and engineering students and corresponding recommendations for increased attention to strategic STEM-related instruction and teacher professional development have emerged. A significant challenge facing urban science and math teachers is a low sense of self-efficacy in teaching STEM content.³ Additionally, a recent large-scale study of teachers revealed that secondary teachers indicated a strong need for help in the area teaching in science, and that a weakness of existing professional development was in the lack of attention to the needs of English learners (EL) and the lack of long-term follow up.⁴ This suggests a significant need for professional development of the type offered in these two RET programs which are the subject of this paper. Intervening with teachers via lesson study and using high quality research in developing middle and high school curricula are important ways of positively impacting student outcomes. These points are essential for strategic interventions connected to professional development for teachers and are precisely the focus of the two RET programs represented in this paper.

A major reason posited for poor student achievement in STEM relates to teachers' preparedness in these content areas. Stigler and colleagues⁵ found that teachers in the United States were quite ill prepared to teach STEM content compared to other nations. In particular, middle school teachers have been found to be quite underprepared due to their limited STEM content knowledge and especially their inability to apply mathematics to science content.⁶ Researchers hypothesize that this may be because the majority of middle school teachers are "generalists" in that they often hold elementary multiple subject credentials and achieve their secondary credential or certification by exam rather than by studying STEM subject matter in depth while in college. With the implementation of the Next Generation Science Standards (NGSS), which have both contemporary engineering and science at their core, increasing both middle and high school teachers' content knowledge is of utmost importance.

While there are many skills necessary to teach science and engineering effectively, deep interconnected subject matter knowledge is crucial in secondary schools.⁷ Researchers argue that in-service STEM teachers, particularly in middle and high schools, fall short in their understanding the depth of contemporary science content and its ties to the engineering they are now required to teach.^{8,9} For example, Parker et al.¹⁰ found that, while high school teachers were most likely to have rather robust science content knowledge, middle school teachers' science knowledge was markedly limited. Only 13% of high school teachers in Parker's research had low levels of science knowledge as opposed to 63% of middle school teachers. In contrast, 56% of high school teachers showed high levels of science content knowledge in comparison to 23% of middle school teachers. The RET programs which are the subject of this paper focused on addressing the content area needs of both middle and high school teachers by immersing them in science- math teacher pairs in cutting-edge computer

science and engineering labs and guiding them in curricular development using their research experiences as contemporary content applied to a lesson study approach.

Programs scope

These RET programs were designed such that computer science and engineering faculty collaborated with middle and high school teachers and their students. The RET programs were comprehensive teacher professional development opportunities in which middle and high school teachers participated in intensive summer research experiences in university engineering and computer science labs, built grades 6-12 curriculum based on the laboratory research content that they learned in the labs and aligned it with NGSS standards, and implemented the new curriculum in their classrooms. The programs have the combined intent of bringing contemporary, innovative engineering and computer science research to middle and high school students, thus improving students' achievement and interest in science, computer science, and engineering through research-based inquiry.

Key activities

The RET programs' design and associated activities included a five-week summer intensive experience in which four days per week (9:00 AM-4:00PM) middle and high school teachers fully participated in engineering/computer science laboratory research and then one day per week teachers engaged in inquiry focused content-to-pedagogy teacher professional development workshops, building curriculum from their lab research experience with foci on scientific experimentation, engineering design, computational thinking, computer science content, NGSS standards and improving students' STEM achievement and literacy. Following the summer intensive research and curriculum building experience, the teachers used the curriculum that they built in their classrooms and engaged in Fall and Spring semester follow-up. Through this, they engaged in collaborative lesson study, studying videotapes of their lessons with one another and engineering faculty with the goal of improving their instructional practices with STEM content foci. This follow-up lesson study approach is a proven form of teacher self-study guided by experts, and science literacy professional development. The teachers' lessons were aligned with the national Next Generation Science Standards, which focus on bringing engineering problem solving to America's K-12 classrooms.

The programs' outcome goals were:

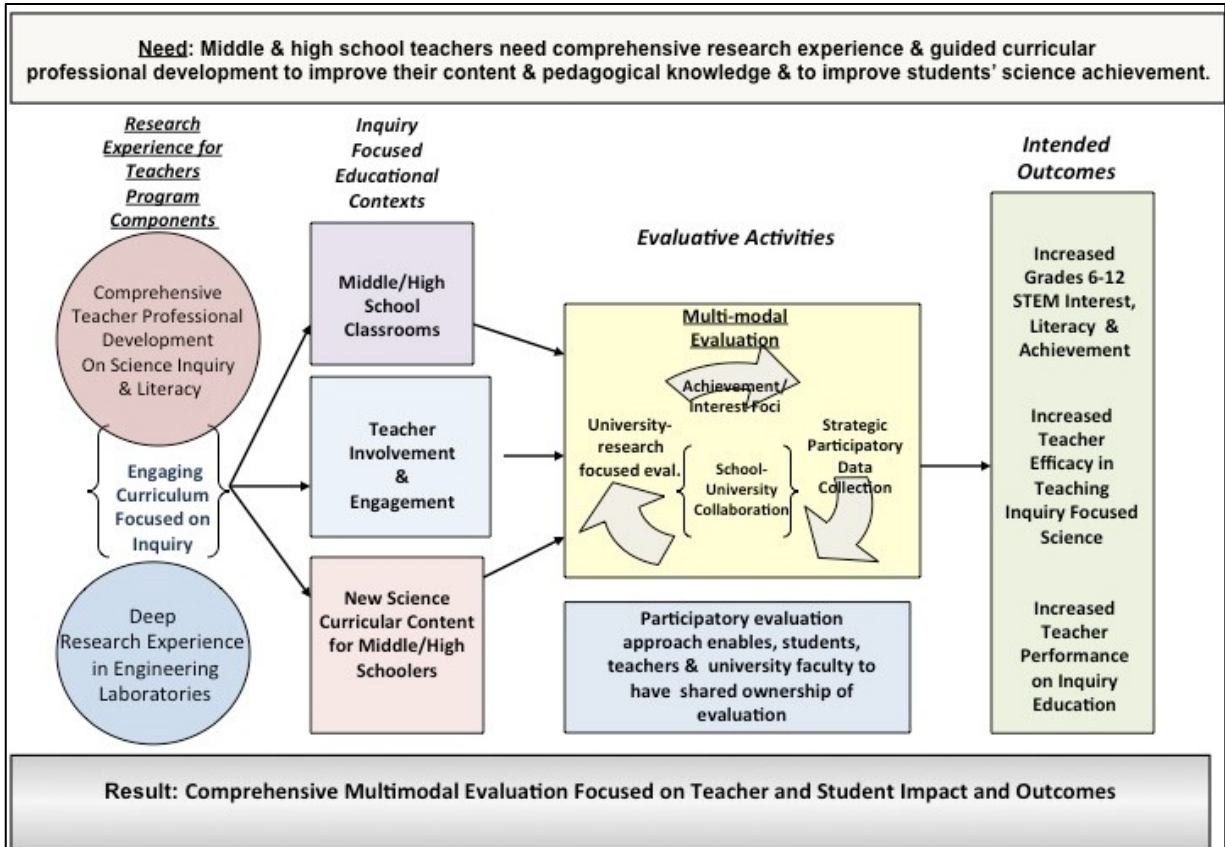
- To increase middle and high school teachers' knowledge of computationally focused science and engineering technologies;
- To increase teachers' disciplinary pedagogic competence in computer science, engineering, and applied math through a comprehensive professional development program that included targeted lab-based research experience focused on computer science (CS) and engineering aligned with NGSS and advanced lesson study;
- To build and maintain long-term collaborative partnerships between middle and high school teachers and the university research community that positively impact student achievement and career paths.

These programs have served middle and high school teachers and their students in urban settings.

To date, we have served 87 middle and high school teachers and their 12,436 students (combined in nine years; 2010-2018). Accordingly, the programs had both broad-based and deep impact on teachers and their students.

Impact focused assessment and results

The RET employed a carefully crafted, outcomes focused logic model that aligned teacher performance with student outcomes. Figure 1 (below) illustrates the links between teacher performance and student outcomes in the professional development model.



This logic model demonstrates how each of the program components related to the intended outcome of the RETs.

Aligned with this logic model, five assessment measures were used to assess the combined impact of the RET programs. Two impact measures were used for teachers and three were used for students. A description of each measure and associated results across the nine program years follow.

Teacher assessments

- Teacher Instructional Performance: This assessment is a rubric scored observational measure of science teacher instructional performance aligned to the state's teacher performance assessment entitled the Teacher Performance Observational Rubric (TPOR).¹¹ Reliability of this instrument is .79 (Cohen's coefficient alpha, NOTE: a score above .70 is considered a statistically reliable instrument). RET participating teachers were observed and their teaching performance was scored based on their instructional performance and practice, which was then compared to a statewide sample of the state's secondary science teachers.
- Science Teaching Efficacy Beliefs Instrument-Revised (STEBI-R secondary)¹²: This assessment is a teacher measure that assesses teachers' efficacy in teaching science to middle school and high school students (in other words their belief that they are a teacher that can improve students' achievement). The instrument includes personal science teaching efficacy (PSTE) and science teaching outcome expectation (the outcomes that they expect from their students, STOE). The measure was administered with the teachers before they enrolled in the RET and after they completed it and teachers were compared to non-participant science teachers that matched the participant teachers' socio-demographic characteristics (using state and national data) to measure impacts of the RET programs on participating teachers teaching efficacy. Reliability of this instrument is .89 (Cohen's coefficient alpha).¹³

Student assessments

- Science Qualitative Reading Inventory: This assessment is a student inventory of science vocabulary, reading comprehension, and science writing achievement and is matched to grade level science content and vocabulary in grades 6-12 science content via NGSS standards. The range of reliability of this instrument is .79-.83 (Cohen's coefficient alpha). Students whose teachers participated in the RET program were compared to those whose teachers did not participate in an RET. Science literacy is an achievement measure and is directly correlated to other science achievement metrics (including standardized statewide achievement tests, $r=.397$, $p<.01$) because ability to read and understand science textbooks is critical to understanding contemporary science concepts and procedures (including experimentation.) The science reading inventory was administered at the start of the year after the teachers completed the RET experience and then at the end of the year to measure the gains in students' science literacy as a function of the teachers' improved teaching from participating in the RET experience. During the RET experience, the teachers received deliberate professional development on how to effectively use science informational texts to improve their students' science literacy.
- Grade and Content Specific Concept Inventories: These inventories measure grade-leveled concepts critical to scientific understanding in middle and high school that are aligned with grades 6-12 NGSS content standards (and in some cases, the math standards). These measures were designed with the RET teachers and were reflective of RET created STEM curriculum units' contents. They also aligned with best practices in

item response theory (IRT).¹⁴ These inventories served as achievement measures of concepts directly connected to the curriculum (lessons) that the teachers created and implemented resulting from participating in the RET. These inventories were administered with students before and after the RET lessons to measure students' achievement in science, computer science, and engineering.

- *Motivation for Science Questionnaire*: This questionnaire measures students' interest, motivation, and engagement in science. Reliability of this instrument is .79 (Cohen's coefficient alpha). Motivation and achievement are directly correlated. Additional motivation and interest in science and engineering correlate with students' effort in science coursework and eventual career interest in science and engineering fields.

Results (2010-18)

The STEBI-R measures teachers' science teaching efficacy. Using nine years of teaching efficacy data (a composite) and comparing to a national and state data set, we have compared the science teaching efficacy of the RET programs participants to other national studies using z score adjusted for multi-construct comparative accuracy. Mean scores for RET participants have been compared to non-RET groups. Table 1 provides the comparison of the teacher participants on the STEBI-R compared to national studies on science teaching efficacy using the same instrument. The RET teachers had a mean science teaching efficacy of 3.81 and the national average (per other published studies) is 2.47. Table 1 also includes RET teacher participants' percentage gains from start to finish of their RET experience in science teaching efficacy (% gains are computed by denoting the sum score differences pre and post rather than 4-point mean gain).

For a second teacher assessment, we have compared teacher instructional performance using a standardized teacher observational metric, the TPOR (for in-service teachers), to the state's statewide averages on a similar measure. The TPOR is a measure aligned with that which is used to measure instructional performance in preservice and in-service teachers state-wide. The mean score on our teacher performance rating (TPOR) for RET participants was 3.91 (partial comparison). The statewide average in single subject science PACT-R rating is 2.89. Our teachers had a 29.7 percent gain pre-to-post RET program (sum scores were used for this percentage gain statistic). Importantly, we recognize that many factors go into improving teacher performance, and that without controlled condition comparisons, predictions of performance indicators are difficult, however our intent is that statistical comparisons to state and national averages reveals promising RET teacher results from the programs.

Full comparative results of the teacher impact measures are indicated in the table that follows (Table 1). Results are presented as both means (or averages) and percentage gains during start to finish of the RET teacher "intervention" time period. These results are based on nine years of combined teacher research and professional development.

Table 1: Teacher Results 2010-2018

Metric	Post – Program Subscale Ave.	Nat’l Subscale Ave.	RET % Total Gains
Teacher Performance (TPOR/ PACT)	3.91	2.89	29.7
Science Teaching Efficacy	3.81	2.47	23.6

These results indicate that the teachers made significant gains in performance and efficacy during the RET program and that the RET teacher participants out performed state and national averages on these two measures. Notably, those teachers who participated in the RET program for more than one year (two years – second year as a mentor) had greater gains than that reported in Table 1 ($p < .05$)

In addition to conducting teacher performance and efficacy measures, we measured changes in student performance of the teachers who participated in the RET programs. Specifically, since one of the RET programs’ intentions were to increase students’ STEM literacy, our curriculum interventions were designed to target content literacy, and we used this metric as a student comparison measure. As such, we designed, administered, and validated a qualitative reading measure for science literacy at both the high school and middle school levels that includes reading comprehension, reading vocabulary in science and writing in science. These data are subject specific and aligned with the national Common Core standards in English Language Arts by grade level, and the new Next Generation Science Standards, and represent subject specific literacy (e.g. physics literacy, biology literacy, life science literacy, or chemistry literacy.) Summative results are presented in Table 2 (2010-2018).

We also measured students’ motivation, interest and engagement in science. This was accomplished via a motivation for science questionnaire, which is a four-point Likert-type instrument with 11 subscales adapted from Baker and Wigfield’s Motivation for Reading Questionnaire.¹⁵

Finally, with regard testing the conceptual knowledge gained from our curricular design that the teachers did during the summer RET, we designed and implemented a concept inventory as an achievement test for each teacher created “unit of study.” We have the following results for the student metrics in Table 2 (combined 2010-2018).

Table 2: Student Results (2010-2018)

Metric	Pre- pgm. % Score	Post –pgm. % Score	% Gains
Science Knowledge <i>(conceptual understanding)</i>	51.1	92.7	41.6
Science Literacy	51.6	93.1	41.5
Science Interest & Motivation <i>(sum)</i>	53.2	90.1	36.9

These multi-year results indicate that the students (on average) made statistically significant ($P < .05$ across measures) gains during their curricular intervention resulting from their teachers' participation in the RET programs. The students gained knowledge, increased their science interest and motivation, and demonstrated gains in science literacy as well.

The student and teacher focused RET programs' results have demonstrated that a teacher intervention can result in student achievement and knowledge gains. These gains are statistically significant, indicating success of the two RET programs across time.

References

1. Ragusa, G. & Mataric, M. (2016) Research Experiences For Teachers: Linking Research to Teacher Practice and Student Achievement in Engineering and Computer Science. *2016 American Society for Engineering Education Conference Proceedings*. New Orleans, LA.
2. President's Council on Advancement of Science and Technology (PCAST, 2011), Report to Congress on the State of STEM Education. DC. 25-37.
3. National Center for Educational Statistics. (1999). *Teacher quality: A report on the preparation and qualifications of public school teachers*. Washington, DC: National Center for Educational Statistics.
4. Gandara, P., Maxwell-Jolly, J., & Driscoll, A. (2005). A survey of California teachers' challenges, experiences, and professional development needs. Santa Cruz, CA: The Center for the Future of Teaching and Learning.
5. Stigler, J. & Heibert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York: The Free Press.
6. Wenglinsky, H. (2000). *How teaching matters: Brining the classroom back into discussions of teacher quality*, A Policy Information Center Report. New Jersey: Policy Information Center.
7. Bybee, R.W. (2010). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher*, 30-35.
8. McConnell, T.J., Parker, J.M., & Eberhardt, J. (2013). Assessing teachers' science content knowledge: A strategy for assessing depth of understanding. *Journal of Science Teacher Education*, 24(4), 717-743.
9. Tretter, T.R., Brown, S.L., Bush, W.S., Saderholm, J., & Holmes, V.-L. (2013). Valid and reliable science content assessments for science teachers. *Journal of Science Teacher Education*, 24(2), 269-295.
10. Parker, J.M, McConnell, T.J., & Eberhardt, J. (2013). Characterizing teachers' incoming science content knowledge in a professional development program. A paper presented at the 2013 Annual International Conference of the National Association for Research in Science Teaching, Rio Grande, Puerto Rico, April 9, 2013.
11. Pecheone, R. and Chung, R. (2006). Evidence in Teacher Education: The Performance Assessment of California Teachers. *Journal of Teacher Education*. 57: pp. 22 - 36.
12. Riggs, I. M. and Enochs, I.A. (1990). Toward the Development of Elementary School Teachers' Science Teaching Efficacy Instruments. *Science Education* 74. 625-637.
13. Ragusa, G. & Mataric, M. (2011) Teacher Training and STEM Student Outcome: Linking Teacher Intervention to Students' Success in STEM Middle and High School Classes. *Conference Proceedings: Annual Meeting American Society of Engineering Educators*, Vancouver, Canada.
14. Wilson, M. (2012) *Constructing Measures: An Item Response Theory Approach*. New Jersey, Lawrence Erlbaum. 29-127.
15. Baker L. & Wigfield, A. (1999). Dimensions of children's motivation for reading and their relations to reading activity and reading achievement, *Reading Research Quarterly*, 34, 452- 477.