Nanotechnology Research Experience for Teachers Enhancing STEM Education

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Nanotechnology Research Experience for Teachers Enhancing STEM Education

Abstract

Teachers serve a vital role in improving the nation's STEM education and inspiring the interest of students. Teachers should be seen as lifelong learners who also need opportunities to enhance their knowledge and spark their own scientific inquiries in order to share this enthusiasm with their students. The Nanotechnology Research Experience for Teachers (RET) fulfills this role by providing Houston area K-12 teachers with unique summer research opportunities at Rice University for over the past six years. RET participants are matched into research groups by their reported interest and work with a research scientist, postdoctoral or graduate student, mentor for a six-week research internship in a faculty laboratory. Teachers gain valuable research experience and deepen their scientific knowledge while simultaneously forming connections between scientific principles, experimentation, and their classrooms. RET participants are guided in these connections via workshops on classroom pedagogy that focus on translating nanoscience and engineering into inquiry-based lessons. The teachers meet weekly during their summer experience to discuss their research, share their experiences in the lab, develop ideas for their students, as well as plan the dissemination of their research, thus forming a collaborative, supportive community. Each teacher creates a poster to present their research experience on the Rice University campus, as well as with their home campus and district or at professional conferences. In the school year following the research experiences, teachers return to Rice to share both their research and lesson plans with other teachers in professional development programs. Participants are also encouraged and guided to publish their nanotechnology lessons through Teachengineering.org. Throughout the components of the program, assessment is performed by an external evaluator to determine the impact on the 13 teachers that participate each summer as well as provide feedback for refining the program. This paper details the RET objectives, program design, evaluation results, as well as the lessons learned, accomplishments achieved, and broader impacts on the community.

Introduction

To be a leader in the global marketplace of the future, the U.S. needs to support a robust STEM (science, technology, engineering and math) pipeline of STEM learners and STEM graduates to meet the demand for a growing STEM workforce. Globally, students in the U.S. still trail those of peer countries when tested in the STEM subjects.[1] The underrepresentation of certain minority groups in STEM fields demonstrates the need for quality education that is inclusive of people from all backgrounds.[2] Prosperity for the future will rest on our nation's ability to prepare for an inclusive and diverse STEM workforce.[3-5]

Teachers are still the drivers and facilitators of any education reform[6-7] and can foster a new generation of STEM learners and professionals.[8-9] However, teachers are struggling to teach effectively and often need to enhance their own content mastery.[10-11] The National Science Standards established inquiry as a focal approach towards scientific learning,[12] which is often more engaging and actively draws students into their own learning compared with traditional modes of passive learning.

As such, teacher professional development (PD) programs have been a choice solution to address these challenges,[13-15] and a research experience can be an intensive form of PD to enhance

teacher content knowledge and effective practice in the classroom. Studies indicate that few teachers have had research experience or inquiry instruction,[12] yet inquiry is modeled on the actual scientific process of discovery and research. Findings show that participation in research opportunities can induce changes in teachers' classroom practices.[16-17] Furthermore, Silverstein et al.[18] demonstrate that the students of teachers who have participated in research improve in their achievement.

In this paper, we report on our Nanotechnology Research Experience for Teachers (RET) program, which is unique based on several features. First, it focuses on ***nanotechnology,*** which is interdisciplinary across STEM subjects and has wide-ranging applications and career prospects that can be effective in engaging students (NRC, 2009).[19] Second, our professional development programs as well as our RET program are grounded in ***inquiry-based learning***. Our RET program recruits primarily from teachers who have had prior inquiry-training through one of our Rice University PD programs. This prerequisite helps assure that the RET experience will be provided to teachers who are more prepared to write an inquiry-based lesson and deliver it in the classroom. Third, our Houston region is comprised of a growing student population that is ***economically disadvantaged*** and may not be receiving equitable opportunities or instruction. Our RET program, given its design and the targeted region, aims to especially impact these students and their teachers. Fourth, our program focuses on nurturing ***teacher leadership***. RET teachers are encouraged to disseminate their experiences and lesson plans to other teachers in their school and district. We also support teachers in presenting at conferences and participating in STEM events. Finally, our RET program is inclusive of ***elementary teachers*** who are often least prepared as science teachers[20-24] and may have the most to gain by research participation.[25]

Program Description

The Rice Office of STEM Engagement (R-STEM) hosts the RET program with a focus on nanotechnology at Rice University. The goal of the program is to provide research opportunities to local K-12 STEM teachers where many serve economically disadvantaged students. In the Houston region, approximately 58% of the public school students are economically disadvantaged with 77% in the Houston Independent School District, our largest school district.[26] The teachers who work with these populations are often the most unprepared[27] for teaching the sciences and thus, can most benefit from the experience and impact their students. The program objectives consist of the following: 1) Use nanotechnology research experiences to enhance teacher content knowledge; 2) Improve the quality of secondary school science education through the development of inquiry-based learning activities centered on research practices; 3) Create a cadre of teacher leaders; and 4) Disseminate the RET outcomes broadly by creating a network of teachers that are actively learning about nanotechnology research.

Recruitment and Participants The RET program recruits from teachers who had participated in one of R-STEM's teacher PD programs. These PD programs, spanning K-12 grade levels, all share the same yearlong training design and inquiry-based approach towards learning. As such, the RET experience continues to build on each participating teacher's foundation on inquiry practice. The teacher programs at R-STEM have grown appreciably through the years (Figure 1). One of the reasons for our programs' success can be attributed to our strong partnerships with over 34 school districts in the Houston area as well as the positive feedback from program participants, which is communicated throughout the community. Our growth not only signifies an expanding reach to teachers and their students in the region but provides the RET program

with a rich and diverse applicant pool. Furthermore, the rapport we establish with our program participants help provide the returning teacher with a more effective and rewarding RET experience. Teachers are more familiar with the campus and our staff as well as some of the research that they may have learned about in a guest lecture or STEM event. They also tend to be more receptive and amenable to the program's expectations.

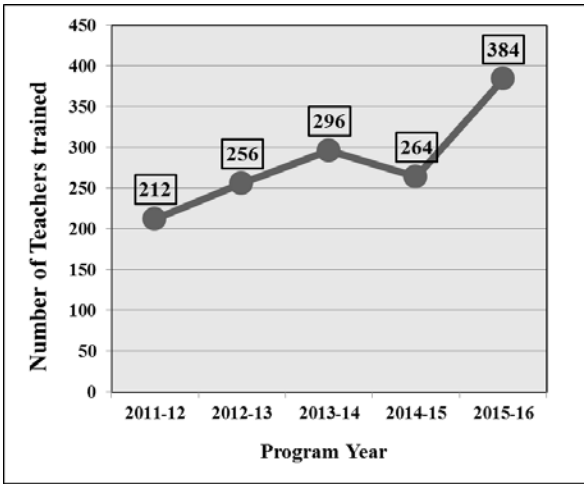

Figure 1. Total number of teachers trained through all of our programs for the past five years.

We select our participants based on several measures including: participation in an R-STEM PD program; subject area they teach; teaching experience; school where they teach; resume; and a personal statement. The overall diversity and dynamic of our RET cohort is considered as well in our final decision process. An applicant's personal statement is heavily weighted in the selection process. Because interviews are not conducted during the selection process, the personal statement allows our office to determine an applicant's purpose for applying to the program, how the applicant's educational goals align with the objectives of the RET program, and if the applicant's current level of understanding for inquiry is aligned with the program's needs.

Since its inception in 2010, our RET program has supported 72 teachers in 14 independent school districts and 47 schools. The current funding period from 2014 to 2016 has supported 39 teachers from 8 school districts and 29 schools. Furthermore, we have supported at least one elementary teacher for each cohort year. Table 1 shows the large applicant pool and how markedly competitive and attractive the program is to these teachers who have participated in one of our programs through their positive experiences.[28] During the three-year period, teachers from a total of 33 school districts and 249 schools applied to our program. The table also shows that elementary teachers are similarly interested in acquiring research experience.

Table 1. The applicant pool for each RET program year.

RET Program Year	Number of Applicants	Number of Schools	Number of School Districts	Number of Elem Teachers
2014	80	63	14	13
2015	206	154	24	63
2016*	94	86	20	19

**In 2016, we recruited one math teacher who was suitably matched to a research project, but he failed to complete the program.*

Table 2 shows the diversity of the applicant pool demographics reflecting the diversity of the teachers in the Houston region.

Table 2. Demographics of the RET applicant pool (2014-2016).

Ethnicity	%	Gender	%
Asian	13%	Female	64%
Black/African American	30%	Male	36%
Hispanic	24%		
White/Caucasian	28%		
Other	4%		

We learned that the main reasons teachers apply to the program include: to learn about cutting edge research and the scientific process to teach students; to use real world experience to engage students; and to be a better inquiry-based learning educator. Participant selection comprised of several factors such as choosing a demographically diverse cohort. Our program diversity shown in Table 3 closely matched the teacher diversity currently in our main and largest school district[26] as well as our applicant pool (Table 2).

Table 3. The RET program participant demographic profile for each year.

Year	#	Gender		Race				
		F	M	White	Black	Hispanic	Asian	Other
2014	13	54%	46%	54%	23%	15%	0%	8%
2015	13	46%	54%	33%	25%	25%	7%	0%
2016	13	62%	38%	8%	54%	8%	8%	23%
Total	**33**	**54%**	**46%**	**32%**	**34%**	**16%**	**8%**	**11%**

RET teachers taught at eight school districts that were predominantly economically disadvantaged with an average of 61% of the students that were classified as such (Figure 2).

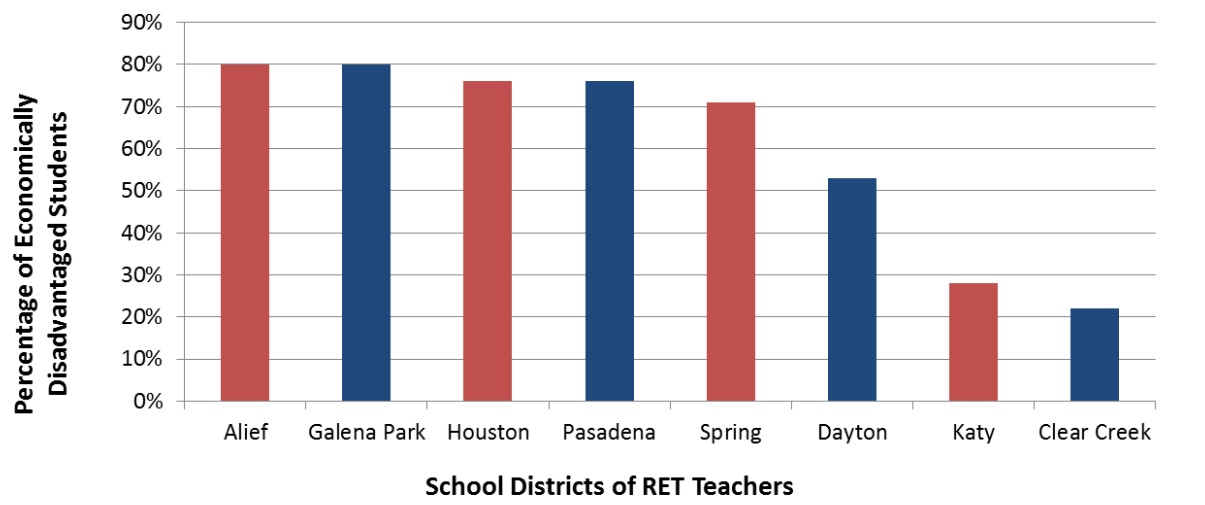

Figure 2. Percentage of economically disadvantaged students for school districts of RET teachers in 2014-2016.[26]

Activities

The RET program annually supports 13 local K-12 teachers who teach a STEM subject in a six-week summer research internship. Once the teachers have been selected, we attempt to match their interests as stated in their application with those of participating Rice faculty and labs. RET teachers are then paired with a post-doc or graduate student mentor from that lab. The mentorship experience has been shown to be beneficial not only to the participants but also provides a valuable experience to the graduate student mentors.[29] One month prior to the start of the summer research, all stakeholders connect so that the RET teacher can be better prepared with background readings and gain familiarity with people and laboratory. Teachers are provided with a Sakai online course account, which they are already familiar with from attendance of a prior R-STEM program. This online account allows them to access or post materials, communicate, collaborate, and participate in surveys.

The official RET summer program begins with an orientation that includes safety training to prepare the teachers for the laboratory. In addition, program expectations and requirements are outlined so that teachers can anticipate and plan for a productive experience. A weekly meeting is held to host guest lectures, to discuss and share exciting lab events that occurred throughout the week, and to work on lesson plans that all participants will develop based on their research. These lesson plans are to be submitted to Teachengineering.org, which is detailed in the meetings. Round robin tours are held so that teachers can learn about each other's research, visit each other's labs, and share their unique experience with others. Rice University faculty also come to speak on various topics in STEM and nanotechnology. To provide RET teachers with a connection to applications of research and an additional field experience, a tour is also offered to a local facility or industrial site.

RET teachers are expected to prepare a poster for the Smalley-Curl Institute (SCI) Annual Summer Research Colloquium, an annual poster symposium held during the last week of the program and a capstone activity to mark the end of their summer research. This symposium is open to the campus as well as the community, providing an opportunity to both disseminate their research findings and gain experience in discussing and communicating about their research to a broad audience. During one of the weekly meetings, a Rice University staff expert from the Center for Written, Oral, and Visual Communication leads a workshop to inform teachers of best practices in preparing for posters. Teachers also were able to rehearse their poster presentations to the group prior to the symposium.

After the summer program officially ends, the teachers continue the submission process of their lesson plans with Teachengineering.org. Teachengineering.org is a peer reviewed website that provides free-to-use lesson plans that are standards-aligned for STEM classrooms. RET teachers are encouraged to utilize their lesson plans within their classroom before final submission. This allows the teachers the ability to create complete lesson plans with questions and instructions that would lead to successful implementation in their classrooms. Our staff helps the teachers flush out ideas for their lesson plans and supports them through the submission process. Teachers also return in the fall to present their lesson plans and/or posters to teachers in R-STEM yearlong PD programs. The dissemination has two purposes: to provide potential future teachers with a complete picture of an RET experience and to provide the RET teachers with an additional opportunity to speak about the research that they conducted during the six-week program. We also maintain our communications with the RET teachers throughout the year, keeping them

abreast of STEM activities and opportunities for engagement. Table 4 outlines the various RET program components.

Table 4. RET Program Timeline.

Timeline	RET Program
Jan-March	Recruitment
May	RET Teachers and Faculty/Lab Mentors Connect
Summer	Six-Week Research Project
	Orientation, Lab Safety
	Weekly Meeting
	Round Robin Tours
	Guest Lectures
	Local Field Experience
	Lesson Plan Development
	Prepare Lesson Plan for Teachengineering.org Submission
	Poster Preparation
	Poster Presentation at SCI Annual Summer Research Colloquium
Fall	Continue Lesson Plan Submission to Teachengineering.org
	Present Lesson Plans/Posters to Teachers in Yearlong Training Programs

Dissemination and Impact

Dissemination of our materials has been impactful on several fronts. Teachers present their research findings broadly at the SCI Annual Summer Research Colloquium. This event is attended by other teachers and students in the community as well as Rice faculty, staff, and students with registered average attendance of over 260 people each year (2014-2016). RET teachers have been cooperative and engaged with preparing and presenting the posters lending way to a successful poster symposium each summer. Teachers also take the posters back to the classroom to share with their students.

Teachers' lesson plans that are developed based on their research are submitted to Teachengineering.org, which is accessible globally. The submission process is iterative and continues after the summer research ends as multiple reviews and edits are sometimes involved. Several teachers have been successful in publishing in Teachengineering.org[30-34] while some are still in progress.

Teachers also come back in the fall and disseminate their research and lesson plans to local area elementary, middle and high school teachers in the R-STEM PD programs with participation captured in Figure 1. Besides taking their material back to the classroom, teachers are encouraged to share their experience with other teachers from their school and district. In addition, a few teachers have been successful in publishing a paper in a journal as well as presenting at a conference.[35-36] We communicate these opportunities to teachers along with information about various community STEM events that might be of interest to the RET teachers.

The broad impact of the three-year RET program is depicted in Figure 3. While only 13 teachers participate in the RET each year, the dissemination of their experiences and lessons online at Teachengineering.org and to the larger group of teachers is compelling. For example, high school teachers in the Houston region typically teach 145 students a year[26] and thus the student impact is far reaching especially in the lifetime of a teacher's career.

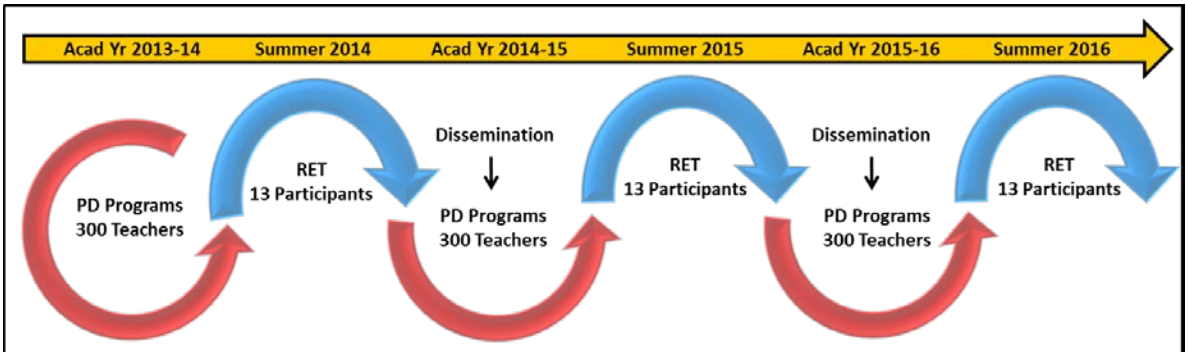

Figure 3. An illustration of the impact cycle of the RET program over three years (over 300 teachers participate in our professional development programs per year).

Evaluation/Outcomes

Teachers were evaluated both quantitatively and qualitatively through an external evaluator. A pre- and post-survey was administered on the first day of summer research and the following January when all components of the program were completed, respectively. The evaluator conducted a focus group interview and lab visits in the middle of the summer. At the end of the summer, the evaluator assessed the RET teachers' posters at the poster symposium. Post-program, the lesson plans were evaluated based on the electronic submissions as well as face-to-face presentations that the RET teachers delivered in the R-STEM courses.

The pre- and post-survey[37] comprised of 20 Likert-type items (Strongly agree = 5 and Strongly disagree = 1) as well as 10 (post) and 14 (pre) open-ended questions prompted teachers to self-report on their perception of pedagogy, teaching philosophy, and inquiry-based learning, knowledge, and implementation. Data from three years of the RET program showed that the largest gains in the teachers' responses were made to the following statement: "*I frequently require my students to apply, analyze, synthesize, and evaluate*" with a pre-survey average rating of 4.14 and post-survey rating of 4.39. This may indicate that the RET teachers are making an effort to effect inquiry learning into their classroom. Table 5 illustrates some of the areas where we observed the most positive gains from the pre- to post-survey.

Table 5. RET pre- and post-survey responses for 2014-2016 data.

Statement	Average Pre-score	Average Post-score
I frequently require my students to apply, analyze, synthesize, and evaluate.	4.14	4.39
Students need to practice basic skills before tackling more complex tasks.*	2.32	2.52
To ensure that students become involved with learning, I often have to go beyond the traditional textbook curriculum.	4.73	4.88
Teachers should strictly follow the sequence of material provided by curriculum if students are to learn the subject matter.*	3.86	4.00
Teaching is largely giving explanations to students and then giving them directions on how to do their assignments.*	3.89	4.03

**Questions were reverse-coded so that higher ratings all correspond to positive responses.*

To note, since these teachers have already participated in at least one of our PD classes, many of them already have a stronger background and understanding of inquiry learning. For example, one teacher remarked the following regarding her prior training in one of our programs:

- The [---] program has provided invaluable inquiry-lesson resources, and our team tries to "shift" existing lab designs into a more inquiry-based model.

Evidence of inquiry practice in the classroom is corroborated by the responses in the open-ended questions of the survey and from the feedback in the qualitative assessments. Teachers were very specific in describing the ways they have incorporated or would incorporate inquiry-based learning in their classroom. These detailed responses suggest that teachers have exited the RET program with concrete strategies that they can implement in their classrooms and with their students. The following are examples of their methods:

- I will have my students develop their own experiments with a set group of materials more often than not. I will let them decide what questions they want to answer.
- In certain labs, students are presented a problem and must develop a procedure to test this problem. They are then left to analyze their data with some guidance.

Here, a teacher demonstrates how inquiry learning can be infused into daily learning:

- I teach a pre-engineering course, so I incorporate inquiry-based learning daily. For example, I like to take real world issues and incorporate them into the class. My students just studied the Flint Water Crisis and afterwards created water filtration devices from everyday materials to clean water.

Teachers were asked about how they could assess student learning outcomes for an inquiry-based lesson plan. In traditional classrooms, tests are the evaluative tool of choice where answers are either right or wrong. To encourage inquiry-based learning, alternative methods for assessment can be considered to inspire a more student-centered environment. Here are some of the creative methods the teachers have devised:

- Reports or presentation at the end of the activity.

- Grading the students thinking process. Not always just grading for right and wrong answers.
- I have started using lab practicums, instead of full tests, as a way to assess learning.
- I prefer using open-ended assessments to see if they can verbally demonstrate their understanding.
- I have the students to using journaling with illustrations to indicate processes they are learning.
- Students have choices in homework projects and focus areas but must first be taught how to do this.

Research suggests that inquiry-based instruction is practiced in limited ways even among motivated and qualified teachers.[38] Thus, we asked teachers about their perceptions on the challenges of inquiry-based learning. These responses include: lack of time, need administration to support teaching reform, and more generally, develop ability to guide students towards a new approach towards learning. Here are some of their responses:

- In the classroom, inquiry based learning is most limited by the time necessary to develop topics in this manner.
- Some students will not have the ability to see the "next step" in their investigation. This can lead to frustration and a negative view of the subject they are studying. It is essential for the teacher to add the component of "guided inquiry" to help the student progress.
- Difficult for low achievers, assessing is difficult, make sure students [are] headed in the right direction.
- The buy-in from administrators and the amount of planning.
- Students who struggle with the content also struggle with inquiry-based learning because they don't know what questions to ask in order to get started.
- The limitations in science are the ability to motivate the student uncover the necessary knowledge and time constraints. Inquiry is a process that is voluntary. Classroom management techniques can encourage participation, and hands on activity can build excitement, but neither of these force a student to inquire.
- Some students like the constant reassurance that they are doing everything correct and are extremely uncomfortable when teachers don't just give them an answer or "yes/no".

The Science Teaching Efficacy Belief Instrument or STEBI[39] was an assessment administered both before and after R-STEM teacher programs. Studies have shown that teachers' self-efficacy can have a strong influence on classroom environment and ultimately student outcomes.[40-41] As a result, we analyzed all the STEBI data for teachers who participated in our training programs both before and after their participation in the RET program. As teachers were required to have been in a program only before the RET and not after, only a limited dataset from eight teachers qualified for this analyses. The STEBI instrument is comprised of two subscales, the personal science teaching efficacy and science teaching outcome expectancy. Although the dataset is small, teachers made a significant gain of 6% in their outcome expectancy ($p<0.05$). This is a promising result as some studies have shown that teachers' perception on the outcome expectancy measure, or their ability to affect actual student outcomes, is often unchanged after professional development.[42-43] This suggests that assessing teachers' self-efficacy both before and after the RET program can provide another informative measure on the intervention.

Lessons Learned

Based on our seven years of administering the RET program, we have learned several key lessons that can inform on creating an optimized RET program design. First, we found that teachers prefer to spend the duration of the summer focused on the research and then prepare their lesson plans later during the school year. To add, teachers also faced difficulties navigating through the publication process on Teachengineering.org. The peer review process is often a new experience for teachers as with the extended time required to complete a publication. Therefore, one solution could be to extend the RET program beyond the summer and create a workshop in the fall committed to lesson plan designing and submission in Teachengineering.org. In this way, this objective can be achieved with more unfettered guidance and separated from the summer program allowing teachers to be fully engaged in their research.

As discussed earlier, teachers often face barriers with implementing their inquiry-based lessons in their classroom. One idea is to host a STEM enrichment workshop for RET teachers to practice and teach their lessons in a lower stakes environment. With the support of their RET colleagues and program staff on site, teachers can receive immediate feedback, which in turn serves as a learning model for the rest of the cohort. Moreover, this provides an additional avenue for dissemination to the community.

Another concern that teachers often express is obtaining support from their schools when they make profound changes in their teaching practice. Implementing inquiry instruction is already a challenging undertaking; teachers are further burdened with curriculum and administrative constraints and lack of peer support. Therefore, by developing strong partnerships with their principals, schools, and districts, such inviting and including them to program events, and bringing them on board as invested team members can alleviate some of these issues.

Both our recruitment data and our experience reveal that elementary teachers are enthusiastic about participating in a summer research. Our elementary teachers have been successful in their research and in fulfilling requirements such as publishing in Teachengineering.org. As corroborated by the literature, elementary teachers have much to gain in building their content knowledge and thus making the RET program open to K-12 teachers should be considered.

The mentorship experience is very important in helping make the summer internship enjoyable and successful for all involved. We received feedback that some of the post-doc and graduate students may not have been adequately prepared to serve as a mentor, hence providing them with mentoring or coaching sessions in advance of the experience would be valuable. This preparation would provide uniform training to all the mentors.

Teachers have expressed an interest to learn about different areas of research aside from their own. This suggests that faculty lectures in diverse subject areas and round robin tours to visit each other’s labs are important components to include in an RET program.

Finally, leadership is important to cultivate since teacher leaders can continue to inspire many teachers and others. Our program has supported teacher leaders by promoting teacher participation in community events and attendance at conferences as well as nurturing a culture of

collaboration and a sense of confidence and motivation. In that regard, a workshop that more explicitly focuses on leadership skills may be a useful component to add to an RET program.

Conclusion

We reported on the unique design of our RET program, which focused on nanotechnology, a cutting edge field in the forefront of the most groundbreaking advances. Its interdisciplinary nature can help connect disparate subject material in education. Another unique aspect of our program is the precondition where we select teachers who have already participated in one of our professional development programs, which are grounded in inquiry learning. This suggests that the selected RET teacher already has strong inquiry-based background and thus can more effectively reap the benefits from conducting research and translating the experience into the classroom. We find from our evaluation feedback that this was the case by the higher level descriptive responses in how teachers did and would implement inquiry learning in their classrooms. We were successful in achieving our goal to recruit teachers who served economically disadvantaged populations in the Houston area. Since our recruits were past participants who have had positive experiences in our programs, our applicant pool year to year was extensive, which allowed us to be selective in choosing candidates who we thought would be most prepared to gain from the program. We observed from teacher responses and the external evaluation that teachers were well on their way towards implementing inquiry in their classrooms despite some of the obstacles intrinsic to practicing inquiry and general education reform. Results also suggest that the program may have positively impacted the RET teachers' self-efficacy. We find that the summer research experience is a valuable intervention to further support teachers who have begun and continue their transformation into inquiry educators.

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