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# Effective STEM Professional Development: A Biomedical Engineering RET Site Project*

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*The Vanderbilt University Biomedical Engineering RET Site Project was created through the National Science Foundation's Research Experience for Teachers program with the goals of giving teachers a broad overview of biomedical engineering, engaging the teachers in meaningful research experiences, and helping teachers to take their research experiences back to their high school science classrooms. Forty-four teachers participated in a twenty-four day summer program with academic year follow-up in which they completed a research project in a biomedical engineering laboratory, designed an instructional unit based on that research experience, and implemented it in their high school classroom. As judged by two attitude surveys given to the participants, this RET program seems to have been an effective program for engaging teachers in meaningful research experiences that allowed them to experience and understand the research process, giving them the ability to relate this to their students. Teachers were able to contribute to the overall research goal of their lab and they were able to complete a small project during their tenure in the lab. Teachers were able to develop an instructional unit based on their research experiences that helped them to bring back into their classrooms what they had learned about STEM research. The teachers' self-confidence grew along with their views of the importance of science research in the classroom and their willingness to seek help. The combination of research and structured instructional materials development based on educational research has created a highly effective professional development program for improving STEM instruction in our high schools and meeting the NSF's program goals.*

**Keywords:** high school; professional development; teachers; biomedical engineering

## RESEARCH-BASED PROFESSIONAL DEVELOPMENT PROGRAMS

THE NATIONAL SCIENCE EDUCATION STANDARDS [1] are explicit in their call for science teachers to create a learning environment that fosters scientific inquiry of authentic questions. This strategy is not supported by having students simply memorize rigid scientific facts in a teacher-centered classroom. Teachers must be provided with the professional development opportunities that increase their own science content knowledge and understanding. They must also be provided with effective teaching strategies and classroom management skills to create appropriate learning environments for their students. [2, 3] Without these types of experiences, teachers do not have the opportunity to modify their own beliefs about the nature of science and are unable to create student lessons and discussions at the mandated level. [4]

Since the 1980s teacher professional development programs have begun to involve teachers in actual scientific research [5–7]. For example, The Teacher in the Woods program [2] provided ecology research experiences for science educators through a five week summer program with academic year follow-up. These teachers received training in forest ecology and field techniques and worked with a scientist on one or more research projects at a site near their school. The program specifically worked to encourage group bonds and to provide opportunities for discussion and reflection. Their university and agency scientists treated the teachers as colleagues throughout the program. This program was found to increase teachers' capacity for providing similar research experiences for their students because their own confidence had been increased. Five years later the teachers reported that the most significant impacts of the program included an acquisition of skills that led to a change in how they taught and gains in subject matter knowledge. They also still valued the beneficial aspect of networking among teachers and scientists.

The GEOTEACH program [4] introduced teachers to the process of superficial bedrock mapping in a three week program. These teachers mastered the field techniques of collecting, interpreting, and presenting data and drew conclusions about the geological nature of the area. The authors of this study suggest that coming to know science as a human endeavor is one success-

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ful approach to helping teachers become more comfortable with and more apt to share the nature of science with their students. In their qualitative research, the authors found that the teachers felt empowered by the chance to 'do real science.'

## ADULT LEARNING THEORY

Adult learning theory should provide the theoretical basis for all teacher professional development programs. One theory of adult learning theory focuses on age. Sheehy [8] reports that as adults move through their late thirties into their early forties they become more reflective, thinking more about context and feeling a greater sense of community. Daloz [9] reports that adults in their late forties and early fifties focus on giving more 'lasting meaning to relationships, work, and spiritual commitments.' Since most teachers fall within these age ranges, it is important that professional development reflect these theories. These theories indicate that teachers will be circumspect about their professional development choices, particularly when they are lengthy summer commitments. This implies that teachers are actually looking to change their beliefs and their professional practices and to have new experiences. Professional development should include time for reflection, either through discussion or journaling, to allow teachers time to 'make meaning of the act of teaching.' [10]

Cognitive development theory shows that adults move from concrete to abstract and from external standards to internal standards. Trotter [10] states that veteran teachers are more likely than beginning to mid-career teachers to be motivated by internal standards of success or by self-affirmation. Functional theory points to the fact that adult learners are motivated to learn if the subject matter is relevant to their current role and transition period and if it was voluntary. Smith [11] adds that the learning environment should be non-threatening and aware of various learning styles.

When viewing adult professional development, Knowles [12] gave several important assumptions about adult learners. Experience was the main resource for adult learning. Adults were motivated to learn when they experienced needs and interests that learning would satisfy. Adults need to be self-directed in their learning. Oja [13] reinforces these ideas about successful adult learning by reporting key ingredients: use of concrete experiences, continuously available supervision and advising, encouragement of adults to take on new and complex roles, and the use and support and feedback when implementing new techniques. Marton and Booth [14] further the importance of experiential learning saying that for learning to be both lasting and meaningful, it must be experienced. Still, these experiential learning experiences can be threatening emotionally when a learner is asked to change his or her subjective framing [15, 16].

## DESIRED TEACHER PROFESSIONAL DEVELOPMENT CHARACTERISTICS

In designing effective science teacher professional development programs, one must draw upon both adult learning theory and the methods needed to develop teachers who understand the nature of science. Science programs should strengthen teachers' skills and provoke greater intellectual rigor, while providing direct and explicit attention to the nature of science [4, 17, 18]. These studies must be of sufficient duration and intensity and adequate resources must be supplied, as the amount of teacher change is directly correlated to these [2, 18]. Garet's study [3] confirms that time span and contact hours have a substantial positive influence on opportunities for active learning that must be accompanied by time for connections among the teacher's goals and experiences, alignment with standards and professional communication with other teachers. Longer activities are also more likely to focus on science content that is critical. Enhanced knowledge and skills as well as coherence of professional development activities have a substantial positive influence on change in teacher practice.

According to Little, successful teacher development communicates a view of the teacher not only as classroom expert but as a member of a professional community with its members often spending 30 or more years in the profession [19]. This community should involve not only other teachers, but also scientists. Though professional development may instill the desire for a teacher to change his or her practices, it is the community network that can help maintain that motivation over time and allow the teacher to feel connected even if no other teachers at their school hold similar beliefs [2]. Communication with peers and collegiality are also important characteristics of an effective professional development program [3]. These peer communications should include time for reflection with respect to the nature of science and personal and professional development [20]. Little reinforces the need for teachers to learn specific, transferable skills and be given the time to evaluate how to incorporate them into their teaching [3, 19].

## RET PROGRAM GOALS

The National Science Foundation (NSF) sponsors a program called Research Experiences for Teachers (RET). The NSF's stated goals for this program have been to support 'the active involvement of K-12 teachers and community college faculty in engineering research in order to bring knowledge of engineering and technological innovation into their classrooms.' In the winter of 2003, Vanderbilt University was awarded a site award for this program to host the 'Vanderbilt Biomedical Engineering RET Site Project.' This program was designed with the previously discussed professional development characteristics in mind and was held in each of the summers of 2004, 2005, and 2006. Our program's specific goals were to educate teachers about the educational research taking place at Vanderbilt through the NSF funded VaNTH ERC, give teachers a broad overview of biomedical engineering, engage the teachers in meaningful research experiences, and help teachers to take their research experiences back to the their high school science classrooms. The VaNTH (Vanderbilt Northwestern Texas Harvard–MIT) Engineering Research Center for Bioengineering Educational Technologies (http://www.vanth.org/) focuses on college level engineering education but has had significant outreach into the K-12 community [21–25].

## GOALS AND HYPOTHESES

In order to evaluate our program goals, the following questions were asked: Could high school teachers engage in a meaningful research experience that allowed them to both do and understand the research process so that they could share it with their students? Could teachers develop and implement high school level instructional materials based in biomedical engineering? Could this program positively affect teachers' opinions and attitudes towards interdisciplinary science and the use of challenge based instructional materials?

Several hypotheses were established prior to beginning this study. Teachers would have the skills needed to engage in meaningful research activities that both benefited them and their students. Teachers would understand the learning theory behind the Legacy Cycle (explained in detail in a following section) and be able to create their own instructional materials that allowed them to teach the required curricular topics through the context of their research project in their home classroom. Teachers would also be able to avoid possible obstacles in implementing their instructional materials. Teachers' attitudes towards the value interdisciplinary science, research in the classroom, asking for help, and the Legacy Cycle would all increase along with their confidence in teaching their subject matter.

## RET PROGRAM DESCRIPTION

Prior to arrival at the RET program, the principal investigator worked with the faculty mentors to develop projects that were within a RET teacher's capability, interest, and time frame that simultaneously complimented the faculty member's research goals. Each teacher was paired with a faculty mentor in the late spring prior to the summer program. This pairing was completed based on the teacher's ratings of the project summaries provided by the faculty mentors and the optional professor's ratings of the teacher's statement of interest in the program and courses taught. Each faculty mentor met at least once with the teacher prior to the start of the program and provided background reading on the research project and introductory safety training as needed.

The RET Site summer program was a twenty-four day program that began with a three day orientation session for all teacher participants. The participants were given an overview of the program and overviews of engineering as a whole, biomedical engineering in particular, and what it means to do both biomedical engineering and educational research. These overviews included presentations by various faculty members as well as brief tours of their labs and facilities. Teachers were introduced to the How People Learn [26] framework and the Legacy Cycle [27] method of instruction. Teachers were trained in one of the nine high school level, biomedical engineering based instructional units that has already been developed and field-tested [21, 22], the Electrocardiogram Mosaic or the LASIK/Optics Mosaic. This training included doing the module just as a student would and then reflecting back on how best to teach that material.

After the orientation session, teachers moved into working with their assigned faculty member for eighteen days. Each faculty member began by providing appropriate orientation and safety training for working in his or her laboratory. Each faculty member also taught appropriate analytical methods for analyzing data obtained in his or her laboratory. More detailed information about the research projects that teachers participated in is provided below.

During the research portion of the program, the RET teachers gathered with the principal investigator for weekly lunches and they were provided with contact information on all teachers to encourage the growth of a community. These lunches were time for sharing accomplishments and frustrations in the lab along with time to discuss teaching as a whole. Two Research Experience for Undergraduate (REU) students visited each teacher in his or her lab weekly.

The RET site program concluded with a three day period where each teacher designed a Legacy Cycle unit of instruction (module) based on his or her research for implementation in their home classroom. Teachers were provided with extensive assistance in this task not only from the principal investigator, but also by the two REU students, as well as their mentor professors to review content.

During the academic year, the PI remained in email contact with the participants. In December of each year, current year participants were required to return to campus for a group meeting. At this meeting, participants reported in on where their module stood. Typically, a few participants would have taught their newly designed instructional unit and were able to share how well it went in their classroom, providing encouragement for the remaining teachers. This meeting also served as a reminder for some teachers that they need to put the finishing touches on their module before teaching it in the spring semester. In the following April, teachers again returned to campus for a final meeting. At this time all teachers reported in on their experiences of teaching their module and plans for revisions. They also turned in a completed copy of their module to the PI, which has become a part of the library of modules available for all RET teachers to utilize.

## THE PARTICIPANTS

Applicants were recruited from numerous area private and parochial schools and in each of the public school systems in the following Tennessee counties: Davidson, Williamson, Rutherford, Sumner, and Robertson. The numbers of applicants in the three years of the program were 42 applicants, 28 applicants, and 26 applicants respectively, and from these applicants 14 teacher participants were selected in each of the first two years and 16 in the third year. In the third year, two teachers were selected from the previous year to return to the program. Teachers were selected for the program based on their statement of why they wanted to attend, their institutional support demonstrated through a letter of recommendation from a department chair or principal, the demographic make-up of the school, their willingness to share their knowledge and spread the materials at their home school and beyond, the geographic diversity of the applicants, the racial and gender diversity of applicants, and the experience level of applicants. Of these 42 unique teachers, the following summary statistics are found:

- 30 (71%) Female, 12 (29%) Male;
- 34 (81%) White, 5 (12%) Black, 2 (5%) Asian, 1 (2%) Mixed;
- 35 (83%) Public, 2 (5%) Private, 3 (7%) Parochial school teachers and 2 (5%) Pre-service teachers;
- 29 high schools and 1 middle school were represented;
- 39 (93%) remain teachers, 3 (7%) have left the profession (1 teacher returned to graduate school in science education, 1 is a principal, 1 is a writer).

The experience of the teachers in the classroom ranged from a teacher beginning her first year of teaching to a teacher with 30 years of experience. The teachers taught a range of high school science, mathematics, and technology subjects with several having experience in more than one discipline. At the time of applying, teachers were not asked about their educational backgrounds (disciplines or advanced degrees), but a recent survey indicated that all but four teachers have an undergraduate degree in science, engineering, or mathematics. Twenty-seven of the teachers have master's degrees, twenty in an education/teaching field and eight in math, science or engineering (one has two master's degrees). One teacher has an Ed.D. in Educational Administration.

## THE RESEARCH PROJECTS

Each teacher worked alone or with one other RET participant in a professor's laboratory. Each teacher completed a small research project designed with their professor mentor. The topics of the research projects varied greatly and reflect the variety of research present in biomedical engineering at Vanderbilt. Table 1 provides representative research topics, which ranged from medical imaging to biomedical optics to nanotechnology. No formal evaluation of the participants research work was completed, although the REU students helped to monitor that adequate progress was being made throughout this time period by holding weekly in-lab meetings with each individual RET teacher. The professor mentors and others in their laboratories also provided the teachers with regular supervision and feedback.

## THE INSTRUCTIONAL MATERIALS DEVELOPED

An important area of cognitive science highlighted by Bransford, et al. was the experimental evidence that while students may have acquired knowledge in previous learning it is not always accessed when needed [28, 29]. This inability to access relevant knowledge in a wide variety of domains was mentioned as early as 1929 by Whitehead who used the term 'inert knowledge' to describe this type of knowledge. Additional work seemed to indicate that traditional educational methods tended to produce knowledge that remained inert [30].

To combat the formation of this 'inert' knowledge, researchers and curriculum designers began to create materials that contained some macro-context around which new knowledge could be generated by the learners. Studies in science [31] as well as mathematics [32, 33], and literacy [34–36] point towards the effectiveness of such instructional designs. This also led the researchers to propose a name for this general type of instructional design, 'Anchored Instruction' [37, 38]. As noted in Bransford (1990):

> The model [Anchored Instruction] is designed to help students develop useful knowledge rather than inert knowledge. At the heart of the model is an emphasis on the importance of creating an anchor of focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems. (p. 123).

An important goal of producing knowledge that is not inert is that it can not only be accessed again in the context in which it was learned but also in new contexts. This concept of 'transfer' has been explored in the literature [39–41]. Serafino and Cicchelli (2003) specifically noted the need for problem-based anchored instruction in promoting students' ability to transfer learning to analogous tasks.

Schwartz, Lin, Brophy, and Bransford (1999) have extended the Anchored Instruction concept to the Legacy Cycle design, which makes use of a strong contextually based 'Challenge.' For example, the challenge for the previously mentioned LASIK/Optics mosaic is 'Your baby brother has broken your mom's glasses (for far-sightedness) for the umpteenth time. She is fed up and would like to consider what she can do so that she never has to deal with them ever again. (She cannot wear contacts!). She looks to her smart kid—you—to help her. So what is her best option? How does it work? Is it safe?' This challenge is followed by a sequence of instruction where students would attempt to 'Generate Ideas' (first thoughts on the challenge), view 'Multiple Perspectives' of others commenting on the challenge and possible ways to address it, participate in extended 'Research and Revise' activities where data and information would be gathered to help the student address the challenge, followed by 'Test your Mettle' a formative self-assessment and 'Going Public' where students' solutions would be made public to peers and others.

Each teacher worked alone or with one other RET participant to develop instructional materials suitable for their high school classroom that were based in their research experience. The instructional materials were designed to follow a Legacy Cycle and to be challenge based. Table 2 provides representative curricula developed by the teachers. No formal evaluation of the teachers' instructional materials was done, but all units were reviewed by both REU students and the PI repeatedly during the final three day period to ensure that the units were following the Legacy Cycle. This process allowed teachers to have the necessary time to consider how they would take what they had learned and share it with their students and to map it to national, state, and local standards. All teachers implemented their modules in their classrooms and anecdotally reported positive feedback from their students.

Table 1. The RET research topics

| **Research topic** | **Research project description** |
|---|---|
| Nanotechnology | The participant worked with Quantum Dots, nano-particles that are currently being used in several different fields of biomedical engineering. One project he worked on is looking at the possibility of placing specific proteins on the dots and then using them to treat various diseases such as cancer. One area of research is looking for ways to use these dots to identify cancers when they are still only a few cells by using specific tags that will bind to the cancers and emit fluorescence while passed through a cell flow cytometer. The participant also worked with DNA by doing some transformation experiments. These were labs that were using the PGlo gene and inserting it into an *E.coli* bacteria. |
| Optics | The participant's lab project involved making skin transparent to light using the osmotic agent glycerol. She measured the amount of laser light passing through a piece of mouse skin with and without glycerol. The set up had to measure light at different angles to find how the glycerol changes the scattering of the light. |
| Microfluidic devices | The participants' lab project used soft lithography techniques to fabricate microfluidic devices. These devices are used in a variety of ways to study different aspects of single cells. |
| Optics | The participant focused on developing an imaging probe that will ultimately enable surgeons to discern between margins of normal versus malignant brain tissue. Currently, the method by which doctors monitor the progress of a patient's tumor resection is by histological analysis of the tumor margin. The process is not without its deficiencies. To improve on this crucial step of the surgical procedure, the project goal was to use antibodies that specifically interacted with malignant glioma cells. |
| fMRI | The participant's project involved fMRI image processing and assessment of what types of motion correction would be appropriate for application to a particular fMRI image depending on a subject's movements during scanning. |
| Imaging | Most of the participants' research experience involved the use of Computerized Tomography. They were able to observe CT scans of small animals and selected objects, as well as human patients. Using computer programs specially designed for this purpose, they were able to reconstruct images by manipulating raw data obtained from these scans. |
| Optics | The goal of the assigned project was to measure changes in tissue molecules in mesenchymal stem cells over a two week period using Raman Spectroscopy. The participant read many articles on stem cells, mesenchymal stem cells, and Raman Spectroscopy, and she learned how to use the Raman/Confocal microscope and visited the stem cell lab. |
| Medical imaging | The participants gained knowledge of x-ray equipment and analog vs. digital imaging. They researched the relationship between planes and projections as well as the effect of noise, contrast and scattering due to the density and atomic make up of matter. |
| Diabetic retinopathy | This participant was involved in a new research study of retinal vascular permeability determined by using dual-tracer fluorescence angiography. If successful, this research will provide a method for early diagnosis of increased permeability in the retinal vasculature before the vessels begin to hemorrhage. This condition could then be treated earlier and could lessen or prevent damage to the eyes of people with diabetes. |

Table 2. The RET-developed curricula

| Research topic | Curriculum description |
|---|---|
| Nanotechnology | This challenge will introduce the concept of adding a gene to an animal that gives it new properties. The class will start off by going over the basic structure and function of DNA. Then they will move into how DNA is made and processed in the cell. After they learn the basics of DNA they delve into how you can change an organisms' DNA by cutting it and inserting a new piece of DNA. The students should learn all about transcription, translation, and transformation. |
| Optics | The participant wrote her module on the nature of light, covering areas such as color, polarization, and the electromagnetic spectrum using a crime scene as the challenge problem. |
| Microfluidic devices | The participants' grand challenge question will involve the possibility of a bioterrorist attack on the water systems of Tennessee by the use of protozoa. The students will investigate different species of protozoa, the effects that protozoa have on human populations, and the velocity of protozoa in the water. Students will design their own microfluidic devices and a velocity 'competition' will be held between the classes. |
| Optics | The participant focused on the simple yet important question of, 'What is light and how do we harness it for our benefit?' In developing mosaics in chemistry, the participant felt that the most encompassing subject is the role of our Sun's radiant energy in affecting the Earth's climate. The grand challenge question will include the movie, 'The Day After Tomorrow'. The teacher would like the students to be able to discern fact from fiction in this very important topic of public policy. In other words, are the sequences of events depicted in the movie scientifically feasible? By going through the cycle of this mosaic, students will cover a significant number of standards relating to electromagnetic radiation, gases, thermochemistry and molecular geometry. |
| fMRI | This participant developed a mosaic centered on epilepsy for use in an anatomy and physiology class. Her grand challenge will require students to interpret fMRI images of a hypothetical epilepsy patient and evaluate whether or not the patient would be a good candidate for surgical intervention. Other challenges focus on brain anatomy and physiology, fMRI imaging basics, and the biological basis of epilepsy. Completion of these three challenges will enable students to respond thoroughly to their grand challenge question, as well as learn about an imaging modality which is becoming increasingly important in both clinical and research settings. |
| Imaging | The Computerized Tomographic module will teach students the anatomy of the brain as it relates to motor function. They will also study the physics behind three biomedical imaging modalities and their application in diagnoses of motor disabilities. |
| Optics | After learning basic optics, the participant decided to use a pulse oximeter to teach cellular respiration. Although the focus will be on the biology of respiration, students will also learn how wavelengths of light are used to measure oxygen saturation of arterial blood. Most students have little understanding that arterial and venous blood are different colors due to wavelengths of light. The grand challenge will involve changes in oxygen levels at altitude using Mt. Everest. The challenges will be (1) Why is oxygen necessary for life? (2) What happens to oxygen levels at altitude? And (3) What are the effects of the change in oxygen at altitude? The teacher will use the video 'Everest: The Death Zone' during the entire challenge. Students will use pulse oximeters to measure their own oxygen saturations as they learn about respiration. |
| Medical imaging | These participants created hands-on, safe, inexpensive means of teaching the relationship between projections and planes (object orientation), the effect of noise and contrast and scattering due to the density and atomic make up of matter. |
| Diabetic retinopathy | The Human Eye Mosaic is a module designed to incorporate current scientific research into the existing classroom curriculum of a secondary level Human Anatomy and Physiology course. The laboratory research used in this module involves the use of a dual-tracer method of fluorescent angiography as a tool for diagnosing diabetic retinopathy in the early stages, thus possibly saving the vision of many people with diabetes. The central focus of this module is Patient X who is suffering from an eye disorder. The students are asked to help diagnose the medical problem of Patient X. |

## ATTITUDE SURVEYS

Attitude is defined as the 'predisposition of an individual to evaluate some symbol or object or aspect of his or her world in a favorable or unfavorable manner' [42]. An attitude survey, shown in Table 3, was given to all RET participants prior to participating in the program (pre-survey) and immediately following the program (post-survey). This survey asked thirteen questions about participant's attitudes towards the importance of scientific research in the classroom, the use of the legacy cycle style of instructional materials, willingness to seek help, confidence in content knowledge, and the importance of interdisciplinary science. Participants were asked to rate their agreement with the given statements on a Likert scale of 1, Strongly disagree, to 5, Strongly agree. Survey content validity was established through a formal expert review. As a measure of survey reliability, Cronbach's alpha was a modest 0.6. This survey was used to assess possible attitude change in teacher participants as stated in the goals and hypotheses of this study. Each of the attitudes being assessed is related to improved instructional materials and methods to better meet the National Science Education Standards.

A second survey drawn from the NSF RET survey conducted by SRI International [43] was completed by the teachers at the end of the RET experience. This survey asked questions about RET experiences, RET outcomes, potential obstacles in the future implementation of knowledge and skills gained during the program. For ex-

Table 3. The RET Attitude Survey

| Question | Category |
|---|---|
| I frequently use examples and problems from other science disciplines in my courses (ex. using biology in physics) | Interdisciplinary science |
| Relating science to the real world through a challenge or engagement question is relevant to the local and national standards. | Legacy Cycle |
| I am confident in my understanding of the content that I teach. | Confidence |
| I do not use KWL (what do you know, what do you want to learn, and what have you learned) or something similar in my classes. | Legacy Cycle |
| Research is applicable in the high school science classroom. | Scientific research |
| I feel uncomfortable using interdisciplinary science in my class. | Interdisciplinary science |
| I regularly use a challenge question or engagement question to frame the students' course of study. | Legacy Cycle |
| Using a technique such as KWL is relevant to the local and national standards. | Legacy Cycle |
| I do not believe that all students need to have a basic understanding of how scientific research is done. | Scientific research |
| Interdisciplinary science is not relevant to the local and national standards. | Interdisciplinary science |
| I do not feel confident in creating a challenge or engagement question to frame my students' course of study. | Legacy Cycle |
| I am comfortable asking my high school colleagues for help and advice when I encounter difficult material in my curriculum. | Asking for help |
| I am comfortable asking professionals outside my school for help and advice in teaching difficult material in my curriculum. | Asking for help |

*Note:* Teachers were asked to rate each statement from a 1 (strongly disagree) to a 5 (strongly agree). The category in which the question fell is provided in the second column.

ample, the survey asked, 'To what extent, if at all, do you think your RET experiences increased your . . .' with stems following that which included '. . . general knowledge base in science, technology, engineering, or mathematics (STEM)' and '. . . confidence in your ability as a STEM teacher generally.' Questions that were omitted from the full NSF survey included demographics questions and program questions for which the answer was either already known or the same for all participants as well as questions that asked about the impact of the RET program on the academic year (which were inappropriate at the end of the summer). Of these questions, the ones that assess the hypotheses of this study were selected to be reported in this manuscript. Most questions were written using a five-point Likert Scale. Some questions had Yes/No responses followed by a second three-point Likert Scale rating if the first answer was 'Yes.' High scores on this survey indicate teacher satisfaction with the RET program itself and a better likelihood of implementing the methods learned and materials created in their home classrooms.

## RESULTS

The total attitude survey scores were compared using a t-test: paired two samples for means. The total score (maximum score = 65) on the survey increased significantly from an average score of $53.0 \pm 5.14$ on the pre-survey to a $56.4 \pm 3.29$ on the post-survey ($p < 0.001$). A Scheffé sub-test was done to compare the three years of the program to see if any differences were found among cohorts of teachers. The only difference found was that the post-test composite score was significantly lower in 2005 than it was 2004 ($54.8 \pm 3.5$ vs. $58.0 \pm 2.7$, $p = 0.04$).

The attitude survey questions were then broken down by category, as shown in Table 3, and compared statistically as shown in Table 4. The categories comprised attitudes towards the importance of scientific research in the classroom, the use of the legacy cycle style of instructional materials, willingness to seek help, confidence in content knowledge, and the importance of interdisciplinary science. No significant increase was seen in the teachers' value of interdisciplinary lessons. Most of the total increase came from an increase in the questions related to use of the Legacy Cycle. Teachers' willingness to ask for help from either other teachers or professionals outside of their schools increased significantly. The teachers' opinions as to how important a role scientific research played or should play in their classrooms were also significantly increased. Teachers' confidence in the content they teach increased significantly. No differences were found on any question among cohorts using Scheffé sub-testing.

The second survey, given only at the end of the program, provided self-reflection data. Teachers responded positively to statements about their own gains from the program as shown in Tables 5–9. These data showed self-perceived growth in the RET's perceived ability to understand research, see STEM applications in the world, and to share this knowledge with their students. RET teachers were also motivated to find new ways to improve

Table 4. The RET Attitude Survey results

| Category | Pre-survey mean | Post-survey mean | Max. score | p-value |
|---|---|---|---|---|
| Interdisciplinary science | 12.1 | 12.3 | 15 | NS |
| Legacy Cycle | 19.3 | 20.9 | 25 | < 0.001 |
| Asking for help | 8.43 | 9.17 | 10 | 0.001 |
| Scientific research | 8.83 | 9.40 | 10 | 0.004 |
| Confidence | 4.45 | 4.62 | 5 | 0.033 |

*Note:* NS = not statistically significant.

Table 5. The RET Self-Reflection Survey. How much do you think your RET increased your understanding?

| | | | **If yes, then how much did RET increase your understanding of this?** | | |
|---|---|---|---|---|---|
| Topic | Yes | No | None | Some | A lot |
| How to conduct a research project | 91% | 9% | 0% | 55% | 45% |
| How scientific knowledge is built | 85% | 15% | 0% | 45% | 55% |
| STEM applications in every day life | 88% | 12% | 3% | 42% | 55% |

Table 6. The RET Self-Reflection Survey. To what extent, if at all, do you think your RET experiences increased your . . .

| **Topic** | **No increase** | **Increased some** | **Increased a lot** | **Have no idea** |
|---|---|---|---|---|
| . . . general knowledge base in science, technology, engineering, or mathematics (STEM) | 2% | 30% | 67% | 0% |
| . . . ability to convey the excitement/vitality of STEM to students | 7% | 26% | 67% | 2% |
| . . . confidence in your ability as a STEM teacher generally | 7% | 33% | 58% | 2% |
| . . . motivation to find ways to improve your students' learning | 5% | 9% | 84% | 2% |

Table 7. The RET Self-Reflection Survey. Have you done or will you do this since your RET?

| | | | **If yes, is your post-RET use less, same, or more than your pre-RET use?** | | |
|---|---|---|---|---|---|
| Topic | Yes | No | Less | Same | More |
| Talked with or counseled students about careers in STEM fields | 88% | 12% | 0% | 9% | 91% |
| Encouraged students to access the Internet to learn more about STEM topics | 88% | 12% | 0% | 16% | 84% |
| Became involved in STEM-related extracurricular activities | 65% | 35% | 0% | 48% | 52% |

Table 8. The RET Self-Reflection Survey. How has your RET experience affected your STEM instructional strategies?

| | | | **If yes, is your post-RET use less or more than your pre-RET use?** | | |
|---|---|---|---|---|---|
| Topics | Yes | No | Less | Same | More |
| Use hands-on activities in your classroom | 93% | 7% | 0% | 0% | 100% |
| Assign projects based on 'real world' problems | 97% | 3% | 0% | 0% | 100% |
| Assign group projects | 77% | 23% | 4% | 0% | 96% |
| Integrate STEM | 90% | 10% | 0% | 0% | 100% |

student learning. RET teaching strategies are now more likely to include the types of activities that are found in true scientific research. The obstacles that teachers face in bringing their new knowledge and lesson plans back to the classroom such as inflexible curriculum, little or no computer/Internet access, the expense of materials, and insufficient time to plan are generally rated not present to minor, with the cost of new equipment and materials being the most prohibitive.

Table 9. The RET Self-Reflection Survey. How much of an obstacle, if any, do you anticipate each of the following will be to your ability to transfer what your learned in RET to your classroom?

| Potential obstacle | Not an obstacle | A minor obstacle | A major obstacle | Have no idea |
|---|---|---|---|---|
| The science topics are too different | 57% | 33% | 10% | 0% |
| The level of science is too high | 57% | 24% | 19% | 0% |
| The school's curriculum is inflexible | 62% | 26% | 12% | 0% |
| School has poor/no access to computers/Internet | 52% | 21% | 26% | 0% |
| Materials, equipment, etc. are too expensive | 26% | 43% | 31% | 0% |
| Not enough time on your part to prepare new lesson/ lab plans, etc. | 33% | 52% | 14% | 0% |
| School administrators are resistant to your proposed changes | 69% | 19% | 2% | 10% |
| Other teachers are resistant to your proposed changes | 67% | 21% | 0% | 12% |

## LIMITATIONS OF SELF-REPORT

All of the data used in this study is self-reported, which implies that it may be exaggerated or enhanced or perhaps the reverse. Though the surveys were completed anonymously, participants may have felt some pressure to please the research team with positive results. We did not investigate the extent to which the teachers' local school contexts or backgrounds may have influenced their responses.

## INTERPRETATION

In order to evaluate our program goals, we began by asking the following questions: Could high school teachers engage in a meaningful research experience that allowed them to both do and understand the research process so that they could share it with their students? Could teachers develop and implement high school level instructional materials based on biomedical engineering? Could this program positively affect teachers' opinions and attitudes towards interdisciplinary science and the use of challenge based instructional materials?

An increase in an attitudinal score on these surveys is important. Attitudes help form the framework for our attention and perceptions. If a teacher perceives something as important, then the teacher will attend to it, and will likely use it. The reverse is also true. If a teacher experiences a shift in attitude about what is important or useful in teaching and learning, then the teacher is more likely to attend to it, and later to use it in his or her teaching. [44, 45]

The initially high results on the attitude survey seem to indicate that the teachers who chose to apply and were selected to participate in this program were already highly confident and competent teachers who saw a need for research in the classroom and wanted to improve their teaching methods. They seem to have learned the most about the Legacy Cycle method of instruction and now value its use as well. Teachers also became more willing to seek and accept help from others through this program, meeting one of the NSF's goals of establishing relationships amongst K12 schools and colleges and universities. While the attitude survey did not show an increase in teachers' support of interdisciplinary science (it was high at the start of the program), the self-reflection survey did indicate that teachers are now more likely to integrate the STEM disciplines in their teaching practice. In the future, this survey will be lengthened to create better survey reliability.

The RET self-reflection survey indicated a great amount of satisfaction with personal growth through the program, especially compared with the national averages reported by all RET programs in 2001–2005 [43]. Teachers in this RET program were not only much more likely to report a positive outcome, but to report that that outcome had changed 'a lot.' Obstacles to the success of the implementation of what they had learned in the RET program were rated lower than those given in the national averages.

It is somewhat difficult to separate the effectiveness and impacts of the Legacy Cycle pedagogical training and the research experience. The research experience provided the teachers with the necessary concrete experience in the nature of science that is desired in effective professional development. The Legacy Cycle provided teachers with an effective framework for bringing the research experience back to their classroom in at least one way. Training in a previously developed biomedical-engineering based legacy cycle instructional unit as well as the entire research experience contributed to the teachers' gains in content knowledge. The design of the program, especially including the research experience, added to the networking that the teachers did both with other teachers and the scientists and engineers. Again, both the research experience and the instructional materials design aspects of the program probably contributed to the reported confidence gains of the teachers.

This RET program seems to have been an effective program for engaging teachers in meaningful research experiences that allowed them to experience and understand the research process, giving them the ability to relate this to their students. Teachers were able to contribute to the overall research goal of their lab and they were able to complete a small project during their tenure in the lab. Teachers were able to develop instructional materials based on their research experiences that helped them to bring back into their classrooms what they had learned about STEM research. The combination of research and structured instruction materials development based on educational research has created a highly effective professional development program for improving STEM instruction in our high schools and meeting the NSF's program goals.

Future RET programs at this university will include some changes to the work presented here. The largest change will be an increase in time spent in the research lab from eighteen to twenty-three days. Increased time in the lab will allow teachers to accomplish more in the research lab, often obtaining more data for their research mentor and improving the utility of the teacher to the mentor. Mentor professors will also be asked to complete a brief feedback form at the mid-point of the research time to provide constructive feedback for the RET teacher. Mentor professors will also be asked to complete a final evaluation of the RET teacher. The PI will also work with each RET teacher to create pre- and post-tests for each instructional unit so that the teacher can better assess the effectiveness of his or her instructional unit as a teaching method. These tests will cover the basic science or math concept covered in the unit (not the research topic in which the challenge question was situated) and will be given to a control classroom as well where possible.

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