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An Engineering Grand Challenge-focused Research Experience for Teachers (RET) Program: Purpose, Outcomes, and Evaluation (Evaluation)

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Abstract
This paper provides details on administering a NSF-funded Research Experiences for Teachers (RET) Site grant. The experience was organized with stratified laboratory research teams solving Engineering Grand Challenge-focused problems. Described here are the research questions and outcomes related to the development and impetus behind stratified teams, and how literature from a variety of disciplines suggests diversity of thought and viewpoint are strongly correlated to high function teams. Detailed also are the types of research activities the teams participated in, the content and focus of the professional development activities, and an overview of the developed lesson plans.

1. Introduction

As an aspect of the extensive K-12 outreach and extension activities of *The Engineering Place* in the College of Engineering at NC State University the authors submitted and were awarded an NSF Research Experiences for Teachers (RET) Site[1] grant. The grant concept involves stratified laboratory research teams working on aspects of NAE Engineering Grand Challenge[2]-focused problems including: sustainability (solar/renewable energy), health (biomechanics), security (computer network security), and joy of living (personalized learning). Each research team includes one tenured engineering/computer science faculty member, one middle/high school STEM-focused teacher, one STEM-focused community college faculty member, one STEM-focused undergraduate education students, and two undergraduate engineering students. Over the course of the three years of the grant, twelve teams (four teams per year) spent six weeks on campus engaged in research and professional development opportunities. The final deliverable of the experience for all teams was development of an appropriate K-12 engineering-informed lesson plan submitted to *TeachEngineering* [3]. The team subsequently implemented lessons plans in the K-12 and community college classrooms during the school year following the summer experience. The project also included research goals to investigate the efficacy of the stratified nature of each team—with participant expertise ranging from student to instructor, and education to engineering—on research and curriculum development. Additionally, we investigated the impact of the summer program on efficacy and attitudes toward teaching STEM. This paper reports on the products produced by teams during the program, and program outcomes based on the quantitative, and preliminary qualitative, results of our investigations.

2. The NSF RET Program

The NSR RET program focuses on creating opportunities for K-12 and community college faculty to engage in research in laboratory settings predominately on university campuses. Built on the same framework as NSF's successful Research Experience for Undergraduates (REU) program [4], RET teacher experiences result in many personal and professional outcomes (e.g. see [5-8]). The NSF describes the program goal as supporting long-term collaborative partnerships that include pre-service and in-service teachers, community college faculty, and research university faculty and graduate students. By providing authentic research experiences, teachers and community college faculty are able to enhance their discipline knowledge of the STEM subjects they teach. These professionals are also able to translate their research experience back to the classroom in order to enrich their students' understanding and practice of STEM, particularly in relation to the field of engineering. Through the partnership formed during the summer experience, teachers will be able to invite researchers and students into their classroom to support their engineering-based classroom activities. A special consideration is given to provide these experiences to inner-city, rural, or high-needs schools, as well as underrepresented persons in STEM (minorities, women, veterans, persons with disabilities, etc.)[9].

RET grants include those attached to other NSF funding as a supplement (Directorates for Biological Sciences, and Directorate for Computer and Information Sciences and Engineering for example) or those that are stand-alone funded Sites. The grant described here was for a funded Site proposal, where several research teams reside at the same location.

3. Approach

This project built upon experience in two prior NSF GK-12 projects, in which the team examined partnerships between students and teachers. In particular, RAMPUP (Recognizing Accelerated Math Potential in Underrepresented People) [10-12] developed an effective model for partnering undergraduate and graduate STEM and education students with in-service teachers. In addition, observations of the team function in the RAMP-UP program led to the hypothesis that stratified teaming had increased advantages.

This premise is supported within the management and psychology literature, where cognitive diversity is used very specifically to indicate the degree of difference in attitudes, beliefs, and task-related diversity (e.g., functional expertise, education, and organizational tenure) among individuals within a working group [13,14]. This is contrasted with the typical definition of diversity that refers to bio-demographic attributes and the difference of an individual from some default population, which has not reliably been shown to benefit team performance [13]. One way to characterize the competencies of team members, and thus the team's cognitive diversity, is through examination of Knowledge, Skills, and Attitudes (KSAs) [15].

Specifically, task-related diversity has been shown to increase team effectiveness on cognitive tasks involving creativity and problem solving [13,16,17]. The management and psychology literature has typically focused on teams within corporate settings rather than academic ones, but by their nature, engineering and teaching both require problem solving, and integrating the topics and practice of engineering research with the extant curriculum in a STEM classroom also requires creativity and innovation. One explanation for the benefit of cognitively-diverse teams on complex, creative tasks is the *cognitive diversity hypothesis* [13,18,19]. The cognitive diversity hypothesis posits that dissimilarity in team makeup (with regard to task-related attributes) discourages *groupthink* and encourages positive member disagreement, debate, and discussion, as well as introducing differing attitudes, perspectives, and knowledge structures [18-23]. Similarly, the *information processing perspective* provides an additional framework to explain how characteristics of team members that are not visible - such as differing knowledge, skills, approaches and professional expertise - provide cognitively-diverse teams a broader base in decision-making activities when searching for information, considering more alternative solutions, and engaging in more vigorous debate before reaching a decision [14,16].

The literature has specifically identified the "real need to develop theory and data on the ways in which dissimilarity among members contributes to task performance," and that "research on diversity in teams should increasingly emphasize the processes that mediate its effects" [17]. As of the latest APA Handbook of Industrial and Organizational Psychology, the varied themes and frameworks for teams and team performance in the management and psychology literature demonstrates *no clear consensus way* of conceptualizing this subject [14,15]. Additionally, the field *lacks causal models* that relate the cognitive diversity exhibited by a team to predicted team outcomes and the contexts in which they can be expected to occur [15]. The dynamic nature of teamwork has led researchers to employ *process* measures to capture the mechanisms a team uses to accomplish its task, in tandem with *outcome* measures to evaluate the teams' products [24, 25]. Researchers have also developed pencil-and-paper measures of communication, some of which are retrospective appraisals of group processes [26], or satisfaction of their teams' communication [27].

Because laboratories are complex systems and team dynamics rely on many factors other than diversity, the program did face some challenges in optimizing the benefits of cognitively diverse teams. Team interdependence, for example is a necessary factor for the benefit that cognitively diverse teams convey [13]. The amount of interdependence in the program varied from team to team. In the personalized learning lab, each RET team was given the chance to work as a unit and pursue their own unique research goal within the broader laboratory context. Members in the sustainability team, in contrast, were often split apart based on experience and content knowledge to serve various different ongoing projects in the laboratory. Individual and team motivation and goals likewise play a role in whether a team derives benefit from cognitive diversity [17]. Even in labs where all team members were working on the same project, individual team members undoubtedly had different goals and motivation for their participation in the summer program.

Project Outcomes: This project placed teams in partner labs focused on one of the four broad areas of the Grand Challenges for Engineering (Health, Security, Joy of Living, and Sustainability), where they performed research for 6 weeks, from mid-June through July, culminating in symposium presentations of research products and lesson plans based on their Grand Challenges area. The Grand Challenges were featured in the approximately 25 hours of professional development participants were engaged in over the summer, along with activities focused on issues in STEM pedagogy and engineering career readiness. Professional development took place through an orientation session, weekly Wednesday lunch talks, and Friday curriculum development sessions. Sustained academic year interactions helped to ensure translation of RET knowledge and experience to the classroom and dissemination to other teaching colleagues.

The broad goal for this program was to build awareness of the utility of using engineering concepts and skills in the teaching of math and science concepts in secondary education settings. In this goal the program fit with countless other programs across the country. The chief focus of this program was tuned more specifically to enhance key competencies of the teachers and the university students related to engineering habits of mind, awareness of engineering as a professional field, and development of self-efficacy related to engineering topics.

Data Collected: Consistent with a mixed methods approach [28], we collected multiple sources of data to evaluate our RET program, including a STEM teaching efficacy instrument, video and observation of classroom lessons, engineering-based lesson plans, laboratory notebooks, and an end-of-summer reflection survey.

STEM teaching and learning outcomes were measured by the MISO T-STEM instrument, which was intended to characterize participant attitudes on entering the program and identify areas of growth due to program participation. The T-STEM (Teacher Efficacy and Attitudes toward STEM) survey is comprised of six scales, each focusing on a different construct related to teaching efficacy of STEM subject and attitudes towards STEM subjects.[3] The scales include: Personal STEM Teaching Efficacy Belief Scale (PSTEBS), STEM Teaching Outcome Expectancy Scale (STOES), Student Technology Use, STEM Instruction, 21st Century Learning Attitudes, Teacher Leadership Attitudes, and STEM Career Awareness (STEMCA) [29]. There is a separate T-STEM for each STEM topic (science, technology, engineering, and math), as well as a separate T-STEMs for elementary. All items are Likert items (1 = Strongly Disagree – 5 = Strongly Agree), and the scales were validated through exploratory factor analysis. Cronbach's Alpha scores were all within the acceptable range (.814 - .948 across all scales) [29]. Table 1 contains a description of each construct, the number of items comprising each construct, and the observed Cronbach's Alpha values from instrument validation. Since there are multiple version of the T-STEM (one for each STEM topic), some alpha values are expressed as a range. Additional qualitative analyses are ongoing but do not inform the focus of this paper, and hence are not reported in this paper.

Table 1: *T-STEM Construct Description, Number of Items, and Alpha Value* [29]

Construct	Description	Number of Items	Alpha
PSTEBS	self-efficacy and confidence related to teaching the specific STEM subject	11	.908 - .943
STOES	degree to which the respondent believes, in general, student-learning in the specific STEM subject can be impacted by actions of teachers	9	.814 - .895
Student Technology Use	how often students use technology in the respondent's classes	8	.869 - .943
STEM Instruction	how often the respondent uses certain STEM instructional practices	14	.934 - .95
21st Century Learning Attitudes	attitudes toward 21st century learning	11	.948
Teacher Leadership Attitudes	attitudes toward teacher leadership activities	6	.870
STEMCA	awareness of STEM careers and where to find resources for further information	4	.945

The T-STEM was administered to all participants using a pre/post-test format. The posttest was administered at the end of the year long experience for Cohort 1 and 2, but we administered the posttest to Cohort 3 at the end of the summer experience to increase response rate. The T-STEM was administered online, collected alongside pre/post short-answer responses, to gauge participant knowledge regarding the nature of engineering, engineering design process, the NAE Grand Challenges for Engineering, and engineering career paths, and others. An end-of-program reflection survey (Cohorts 2 and 3) asked participants to reflect on the impact of the program on their future practice, and regarding their satisfaction with the program. We also collected qualitative data (analysis ongoing for Cohort 3) to explore experiences and group interactions of the participants. Participants were asked to keep laboratory notebooks during their 6-weeks of research, and these were collected to document process and practice, participant attention, and technical accuracy. Finally, we collected data regarding the research and education outcomes of the program, including related to the number of participant demographics, as well as the types of research support provided to host labs, and the curricula created by each lab team.

Data Analysis: Data from the T-STEM were coded (where applicable) [29] and each scale was constructed by summing a participant's responses to each item comprising the scale and dividing by the number of items summed to maintain the original metric of the instrument. Pre/post test scores for each group were evaluated using a paired samples t-test. Meanwhile, data related to number of participants and the research support provided to host labs was summarized using descriptive statistics.

4. Results and Discussion of *Program Impact:* The program has served 63 participants: 11 community college instructors, 14 K-12 teachers, 10 pre-service teachers (education undergraduates), 24 engineering undergraduates, and 4 university faculty at NC State University and UNC-Charlotte hosting participants in their laboratories. K-12 teachers have come from various school districts: Durham Public Schools (4), Charlotte-Mecklenburg Schools (5), Wake County Public Schools (4), and one charter school, including several Title 1 funded schools and schools with a STEM focus. Community college instructors were selected from six local institutions: Isothermal Community College (1), Rowan-Cabarrus Community College (1), Stanly Community College (1), Wake Technical Community College (3), Fayetteville Technical Community College (2), and Durham Technical Community College (2). Many undergraduate engineering participants were from underrepresented groups: 15 women and 8 minority students.

Summer professional development led to the creation of 18 engineering lessons and activities, integrating with course topics in mathematics (8 lessons), biological and physical science (13 lessons), and CTE/Engineering (4 lessons), and spanning from middle grades (4 lessons) to high school (10 lessons) and community college (4 lessons). These lessons are currently at various stages in the revision and submission process at *TeachEngineering.org*, a peer-reviewed repository of standards-aligned engineering curricula. Lessons were enacted by participant teachers and instructors prior to lesson plan submission; video data of the enactments were collected for Cohort 2, and recordings are in process for Cohort 3 (2018-2019). These data, once completed, will contribute to a publication regarding the quality and content of teacher-developed integrated STEM curriculum.

Participant attitudes toward STEM teaching and learning, measured by the T-STEM instrument developed by the Friday Institute [29], were assessed before and after participation in the year-long program (for Cohort 3, post-tests were administered at the end of the summer program to improve response rates and assessment validity). Use of the T-STEM was intended to characterize attitudes of the participants upon entering the program and determine areas of growth due to program participation.

As previously noted, our initial data collection strategy involved gathering pre T-STEM measures at the start of the RET experience for each cohort. Post T-STEM measures were then collected after all RET activities concluded for the cohort, almost one full year later. This approach limited the number of post-test responses received, we changed the data collection strategy for the third cohort, collecting post-test measures at the end of the summer experience. There was also significant variation in the number of post-test measures, within the constructs as not all participants chose to complete all items.

Preliminary analysis using paired samples t-test to compare mean difference of the pre/post-test scores revealed statistically significant improvement in two constructs: Personal Teaching Efficacy and Beliefs (PSTEBS) and STEM Career Awareness (STEMCA). The PSTEBS was significantly improved ($t = -2.31$, $df = 21$, $p < .05$, $n = 22$) from a mean pre-test score of 3.75 (SD = 0.57) to post-test score of 3.95 (SD = 0.69). We calculated Cohen's *d*, and the observed effect size fell into the medium category ($d = 0.32$) Similarly, the STEMCA improved ($t = -4.10$, $df = 23$, $p < .001$, $n = 24$) from pre-test (3.64, SD = 0.55) to post-test (4.24, SD = 0.69) with a large effect size ($d = 0.96$). Results indicate participants' personal teaching efficacy and awareness of STEM career options increased after participation in the RET program. Interestingly, another construct of the T-STEM, STEM Teaching Outcome Expectancy Scale (STOES) decreased between the pre/post-tests, although without statistical significance. STOES measures how strongly teachers feel they can influence their students' learning and classroom outcomes.

An end-of-summer reflection survey collected qualitative data to explore experiences and group interactions of the participants and help guide future implementations of the program. These survey data are undergoing analysis, and preliminary results suggest participants felt the program was strong in areas of Communication and Collaboration, Engineering Content, and Education Content. Relatively few participants cited the Grand Challenges as an area where they felt they learned the most. Of the participants that did respond to the prompt regarding the Grand Challenges, many of them only discussed the specific area of their lab's research, rather than the four areas or twelve challenges specifically. One teacher responded on how learning about the Grand Challenges would be beneficial to her students:

> *Prior to participating in this program, I did not know about the concept of Grand Challenges for Engineering. I think that this would be a very important concept to teach my students when introducing engineering, so that they can see how it is relevant on a global level.*

Another teacher responded on a personal level on how the Grand Challenges reflected modern engineering problems,

> *It gives us a better perspective on how research works. This is what it feels like to be on the forefront of cutting-edge research.*

These responses indicate the Grand Challenges have the potential to provide valuable insight which teachers can translate into their classroom, but that our program, in the following years, should find ways to make this a larger and more explicit part of the professional development.

To assess participant perceptions of their own contribution and the contribution of their group members, laboratory staff, and program staff to the summer's outcomes, a Likert-scale survey was administered to Cohort 3 (16/20 participants responded) at the end of the summer program. Preliminary results reveal participants felt strongly that their "group members brought unique skills and perspectives to the research project" (93.8% agree or strongly agree) and that their "group members brought unique skills and perspectives to lesson planning" (87.5% agree or strongly agree). Participants also felt "group members contributed equally to the research project" (81.3% agree or strongly agree), and "group members contributed equally to lesson planning" (81.3% agree or strongly agree). These results support the idea that the cognitively-diverse teams assembled for our current RET site were productive and functional, and it provides a foundation for the analysis of our entire body of data as a whole.

This professional development led to the creation of 18 engineering lessons and activities, integrating with course topics in mathematics (8 lessons), biological and physical science (13 lessons), and CTE/Engineering (4 lessons), and spanning from middle grades (4 lessons) to high school (10 lessons) and community college (4 lessons). These lessons are currently at various stages in the revision and submission process at TeachEngineering.org, a peer-reviewed repository of standards-aligned engineering curricula. Lessons were enacted by participant teachers and instructors prior to lesson plan submission; video data of the enactments were collected for Cohort 2, and recordings are in process for Cohort 3 (2018-2019). These data, once completed, will contribute to a publication regarding the quality and content of teacher-developed integrated STEM curriculum.

Teams produced valuable research support to host labs, including data analysis that ultimately supported publications, conference presentations, and grant proposal development. Teams contributed to 26 research projects over the three year project period; examples include fabricating transparent electrodes for integration into semitransparent organic solar cells; altitude optimization for airborne wind energy systems; and analysis of computed tomography images to characterize bone shape changes after nerve injury. The work produced by the teams supported 2 grant proposals, 8 conference papers and abstracts, and 6 journal publications in preparation or under review. Importantly, 11 team members continued to work with host labs following their summer experience, with approximately half the undergraduate engineering students expressing continued interest in research and pursuing graduate studies. Participants assisted host labs in development of 18 research outreach modules for lab tours and other K-12 activities, outside of the classroom lesson plans developed through the RET. Examples include an ocean current turbine design challenge and an electromyography (muscle activation measurement) demonstration augmented to include audio feedback for visually impaired students. The faculty reported that in addition to tangible research benefits, the experience of hosting teams resulted in mentor development in supporting multiple mentees and research projects at once, mentoring experience for other lab members including graduate students, new perspectives for projects from non-experts, and awareness of STATE K-12 teaching standards.

5. Conclusion

The RET program was created by NSF to give teachers and community college faculty members exposure to engineering and computer science research, providing them greater depth and breadth of topical areas researchers investigate. The research experience is meant to provide experiences that teachers can draw upon when developing curricula in their classes. By integrating engineering and computer science concepts and ideas in the teaching of other subject matter, students gain exposure to engineering concepts and ideas, with the goal of a greater interest in engineering and computer science.

Broadly, we are able to discern that the program site at NC State University met many of its outcomes. Participants indicated an increase in knowledge of engineering careers and efficacy related to teaching engineering concepts. The lab environments in which our teams worked during the summer provided hands-on opportunities for teachers, engineering students, and pre-service teachers to gain awareness of engineering habits of mind and examples of the types of problems engineers work to solve. By supplementing the lab environment with weekly workshops on teaching and learning, our participants were able to create lesson plans that incorporated engineering concepts and ideas into the teaching of math, science, and technology. Analysis of the participants' lab notebooks is ongoing, in an attempt to identify how the RET program facilitates the transfer of authentic STEM practices from the laboratory to classroom setting.

The stratified team approach also brought a diversity of thought to the problems being studied in the labs and ultimately to the development of the lesson plans. While there is a large amount of literature that supports the approach, our experience has demonstrated that fostering a diversity of thought on teams is beneficial to enhancing team efficacy. Our future research will begin to investigate how stratified teams, such as discussed in this paper, facilitate the positive outcomes detailed. Understanding the mechanisms through which diverse teams foster beneficial outcomes should help researchers and practitioners better understand the ways in which teams can be constructed to maximize potential.

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