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RESEARCH EXPERIENCE FOR TEACHERS: A ROAD MAP FOR EDUCATIONAL ENHANCEMENT AND GROWTH IN STEM ENROLLMENT TRENDS

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ABSTRACT

Scientific research and development represent an essential element in supporting and improving education systems in the United States (U.S.). To equip the K-12 teachers with scientific discoveries, new technologies, and research significant changes in curriculum and teaching standards is required such that student's interest in STEM fields of study grow more. One of the very successful initiatives funded by the National Science Foundation (NSF) that works on achieving the above goals is the Research Experiences for Teachers (RET) in Engineering and Computer Science. The program was released on 2001 with the aims at laying the early foundation and igniting the spark for R&D in K-12 by involving a selected group of qualified teachers in a practical, applied, research university atmosphere. RET goals are not only to instruct the participants (i.e., teachers) on research process of the STEM in real-world applications but also to convey a new perception of science and technology to their students thus encouraging them to pursue careers in engineering and computer science. In this paper, we provide the milestone that is essential for developing a successful RET program and discussed the program's positive impact on the U.S. education systems and progress of student STEM enrollment throughout the nation.

Keywords: Research Experience for Teacher, Education, K-12 teachers, STEM enrollments.

INTRODUCTION

Many US students conclude early education stages that Science, Technology, Engineering, and Mathematics (STEM) subjects are annoying, too tricky or unwelcoming, leaving them ill-prepared to meet the challenges that will face their generation, their country, and the world. In 2007, the National Science Board [1] reported that the STEM education in the US is failing to motivate US citizens to obtain adequate knowledge and skills required to meet the century's challenging economic and leadership needs. Due to lack of proper motivation, many of the high-STEM-ability US students fail to realize their STEM potential in high school or quit from the STEM track in college.

STEM education is vital at the K-12 level when students develop a foundational understanding of STEM concepts and form opinions about their career choices. The National Society of Professional Engineer's (NSPE's) Position Statement No. 1768 [2] on STEM emphasizes the changes that are required to be implemented at the K-12 levels in order to develop more STEM professionals. Studies conducted by the National Academy of Engineering (NAE) have found that middle and high school students are greatly influenced by their teachers, and to increase the number in STEM education, it is essential to equip the middle and high school teachers with scientific discoveries, new technologies, and research. This will lead to significant changes in curriculum and teaching standards.

According to the Engineering Workforce Commission (EWC) [3] report of 2005, over the past 20 years, the total number of the US students who received bachelor's degrees in engineering is declined by 19.8%. It becomes a challenge for many high schools in the US to get a sufficient number of students to choose to enroll in STEM-related academics. The ACT Policy Report [4] of 2003 found that the interest in science and engineering among high school seniors is declining since 1991, as shown in Table 1.

From 1995 to 2004, the ratio of freshmen planning to enroll in STEM fields declined. In 2004 the overall high school student interest in the STEM was 20% which is increased, slowly but gradually, by over 25% in 2016. The K-12 teachers can influence their students to pursue STEM majors after high school. To equip the K-12 teachers with scientific discoveries, new technologies, and research lead to major changes in curriculum and teaching standards which increase the student's interest in STEM education.

To address the barriers and problems of STEM education, we need to target the middle and high-school students and teachers. To co-op with the nation's needs in STEM education, meaningful preparation of STEM teachers needs to be considered as an indubitable requirement. STEM initiatives should be monitored by the Department of Education and other federal agencies. For example, the National Science Foundation and the National Council of Teachers of Mathematics. Thus, the US must provide more investment in supporting teacher preparation, training and research programs which can provide an effective content and pedagogical knowledge for all STEM subjects.

Table 1: Potential Engineering Majors [4]

High School Class	Number
1991	63,653
1992	66,475
1993	67,764
1994	64,571
1995	64,937
1996	63,329
1997	63,601
1998	65,329
1999	65,776
2000	61,648
2001	54,175
2002	52,112

The NSF's Directorate for Engineering and Computer & Information Science & Engineering (CISE) has pursued some of these initiatives jointly in 2001, by awarding funds for RET in Engineering and Computer Science program [5]. RET program supports active long-term collaborative partnerships between K-12 STEM in-service and pre-service teachers, full-time community college faculty, a university faculty and students to enhance the scientific disciplinary knowledge and capacity of the STEM teachers and community college faculty through participation in authentic summer research experiences with engineering and computer science faculty researchers. The estimated RET Sites program budget for each fiscal year is $5.8 million.

The RET pipeline of teachers-students shall have a great, self-motivation and open career opportunities for students. The last decade witnessed an increased interest in majoring in the STEM. There is a strong connection found between the RET program and STEM interest among students. The RET programs allow middle and high school students to get hands-on experience in engineering and computer science research. Thus, student achievement and interest in STEM majors shall be improving. RET program goals are not only to instruct the participants (i.e., teachers) on research process of the STEM in real-world applications but also to convey a new perception of science and technology to their students thus encouraging them to pursue careers in engineering and computer science. The K-12 teachers can influence their students to pursue STEM majors after high school, and this will lead to the growth in enrollment trends in STEM fields.

This paper aims at providing the milestone for developing a successful RET program, discussing the significance, positive impact on the U.S. education systems state-by-state, and give some statistics on the progress of student enrollment throughout the nation. Section II presents the overview and action plan of the RET program. Section III discusses the significance of RET programs for US STEM education. Section IV presents the case studies and findings of successful implementation of RET programs and its broader impact on the STEM education. Finally, Section V offers some concluding remarks.

WHAT IS THE RET PROGRAM?

The RET programs are comprehensive teacher professional development opportunities in which middle and high school teachers participate in intensive summer research experiences in university computer science and engineering labs, and build K-6 to K-12 curriculum based on the research content that they learn in labs, and implement the new curriculum in their classroom. The vision of the NSF RET programs is to help build long-term collaborative partnerships between K-12 STEM teachers and the NSF university research community in order to bring knowledge of engineering and technological innovation into K-12 classrooms. The essential elements of the RET program are:

1) quality education;
2) content, curriculum and learning materials;
3) educator training and support;
4) policy, management, and systems; and

5) approaches and illustrative entry points.

The action plan for RET consists of the activities which can be monitored and measured. An action plan for the development of RET is shown in Figure 1. The RET plan includes the following four phases.

- Planning and feasibility study
- Coordination and Training
- Implementation
- Follow up

RET programs can be in Manufacturing, Artificial Intelligence, Gaming, or Business. The selection should be based on the available resources at the university, the experience of the university teachers in the field and the programs of study of K-12 students. After the planning and feasibility study phase implemented, we can move to the coordination and training phase.

Fig. 1. An action plan for the development of RET

A. Planning phase

In this phase, we need to coordinate the work between a university and a number of schools in a district. The purpose of the planning phase is a number of folds:

- Establish the system requirements,
- Define the schedule, cost and expected a list of deliverable and dates,
- Develop a work plan,
- Get management acceptance.

A number of selected teachers based on competition shall be chosen to get involved in this program. Each participating teacher should be able to enrich his or her own-knowledge-base as a STEM education professional and an active member of a research team.

The RET model shall include regular teacher-faculty interaction in various formats. The RET model plan consists of a series of activities for teachers that will include seminars and presentations on research methodology, technical writing, and professional ethics. The first week of the RET program shall comprise an orientation week that provides an introduction to STEM, training in research methods and ethics, and schedule and plans for teacher-faculty interaction.

Week 2-5 shall bring teachers together as an entire group to develop, share and discuss approaches for integrating the research experience. Week 6 of the RET program will bring all of the teachers together for final presentations of their group project, discussion, and summative evaluations.

The nature of teacher activities during the RET program shall be:

- **Orientation Session**: The various research programs of the institutions will be introduced to the teachers through a short presentation.
- **Teacher Disciplinary Background**: To provide the requisite background to the teachers having little or no prior research experience. Accordingly, short courses shall be designed and offered by the faculty researchers to review essential introductory material for developing the necessary skills and concepts befitting their research activities.
- **Mentoring the Mentors**: Selected graduate students having prior experience in research topics will serve as mentors. These students shall gain relevant experience through the prior course and research work. These selected students must undergo training for this role.
- **Research Projects and Teachers Activities**: The group of teachers shall be working together on a research project with a faculty mentor. All teachers will receive information concerning the faculty mentor and project partners assigned based on their interest and background.
- **Scientific Research Activities**: The RET program shall include regular teacher-faculty interaction in various formats.

Some of these activities include:

1. **Weekly Paper Discussion Session**: This session allows the teachers to review and discuss contemporary papers relevant to their projects. A faculty mentor will be responsible for supervising the paper discussion session and will guide teachers whenever difficulty is experienced.
2. **Weekly Group Summary Meeting**: Teachers will meet their faculty mentor and discuss accomplishments and challenges regarding their project and seek advice accordingly. A weekly group summary meeting will be the final meeting of the week. From weekly meetings, teachers will develop a sense of cohesiveness among themselves, an understanding of the interrelationships and interdependencies of their work, and a sense of ownership of the entire project.
3. **Plans for Teacher-Faculty Interaction**: The activities related to research will include finalizing the requirements of the research project, writing and presenting a proposal on the research project, writing and presenting a midterm progress report on the research project, and then writing a final report and making a final presentation.

Finally, during the last week of the RET program, the teachers will submit their final research report and present their research findings, and faculty mentors will evaluate their presentations. The final presentation will be attended by the faculty mentors, invited guests, academics, administrators, graduate, and undergraduate students.

B. Coordination and training phase

In this phase, RET shall be implemented to fit the needs of school teachers. Although the teachers may appear as the central link in the proposed project, the broader impact is multi-face affecting the scientific and educational environment in multiple ways including:

1. Teachers shall have a better understanding of the R&D process and the scientific methods for planning and conducting research.
2. Collaborations with counterparts from many schools and universities, are possible, and would also provide new educational and scientific perspectives.
3. Students are the direct beneficiaries of the learning modules developed by the teachers and indirectly by the new and improved teachers understanding of the research process.
4. Interactions among mentors and researchers are likely to generate scientific collaborations that extend beyond the RET program.

C. Implementation phase

A possible plan for teacher role can be summaries as follows. Teachers will spend six-to-eight weeks on the university campus working in a laboratory research group. Training period shall include developing background literature on specific research projects, a state of the art of the current research on a selected topic, and general ideas regarding possible opportunities. Teachers then work with their mentors to develop their research questions and research plan. They shall enhance their learning outcomes to the curriculum and make integration of the research into classroom learning modules. Topics from sample projects selected during the training phase shall be part of a term project for teachers. Face-To-Face events and informal asynchronous communications via the program website shall be implemented. Teachers shall get a chance to attend a research workshop to present their gained experience and research thoughts. A vital feature of the RET program is that it gives the teacher the ownership of the research question/direction, not the mentor. During the first academic year, the group of teachers will meet every 3-4 months to coordinate project activities, scientists, and education specialists to explore ways to merge scientific research techniques into the K-12 science curriculum.

D. Follow up phase

Follow up, and assessment activities would be planned to increase the ret impact on the educational environment in the participants' classrooms. Teachers will be back on campus in the second year to show their progress, achievements and success stories for other teachers as well as a science educator and researcher. During the second academic year, teachers will meet approximately every 3-4 months to refine their curricular materials for the annual workshop.

THE SIGNIFICANCE OF RET PROGRAMS ON UNITED STATES STEM EDUCATION

The concern of government agencies, national organizations, and private industry has been growing over the declining state of STEM education. The successful implementation of programs (like RET) that partner students, teachers, and scientist together improve the STEM enrollment trends in the nation. The NSF provided funding for many RET programs across the United States. The NSF's expectations for these RET programs are that they will lead to an effective curriculum that integrates engineering into the STEM disciplines. RETs are summer research programs where middle and high school teachers are committed in a full-time position, to work in industry or hosted by a research lab, for 4-8 weeks during the summer. The expected RET Sites program budget for each fiscal year is $5.8 million [6]. The number of awards anticipated per year is between 8-10 awards. The anticipated funding amount is $600,000 for a duration of up to 3 years. RET supplements are limited to $10,000 per teacher for a period of 1 year. Subject to availability of funds. Total 2517 number of awards are awarded by NSF for the RET programs in the US. Table 2 displays the number of grants for RET programs, state-by-state in the US, funded by NSF.

From 1995 to 2004, the ratio of the freshmen planning to enroll in STEM fields declined [8], and it was hitting a low of 20% in 2004. The US 20-year trend in the overall STEM interest has been rebounded and continues to increase slowly, as shown in Figure 3.

Table 2: NSF awards for RET programs [5,7]

STATE	# Expired Awards	# Active Awards	Active Awards Amount
Alaska	1	0	-
Alabama	40	7	$41,620,662
Arkansas	16	1	$301,753,536
Arizona	52	11	$319,353,156
California	149	33	$783,079,314
Colorado	57	19	$544,127,460
Connecticut	17	9	$262,818,642
District of Columbia	15	3	$110,110,002
Delaware	12	0	-
Florida	97	21	$834,312,228
Georgia	92	16	$269,604,408
Hawaii	13	0	-
Iowa	32	9	$140,997,744
Idaho	5	3	$97,008,000
Illinois	86	12	Not Available
Indiana	58	18	$542,807,418
Kansas	28	6	NA
Kentucky	11	6	$168,672,096
Louisiana	16	5	NA
Massachusetts	112	27	$369,801,546
Maryland	66	8	$84,486,918
Maine	22	4	$260,295,870
Michigan	64	14	$798,913,896
Minnesota	32	11	NA
Missouri	27	6	$168,857,370
Mississippi	16	5	$114,023,034
Montana	11	2	$167,628,132
North Carolina	46	16	$360,618,216
North Dakota	3	2	$165,679,794
Nebraska	15	5	$168,787,998
New Hampshire	15	2	$169,200,000
New Jersey	26	8	$138,069,738
New Mexico	18	4	$81,211,488
Nevada	8	6	$485,342,586
New York	139	37	$310,200,000
Ohio	71	8	$387,650,736
Oklahoma	25	10	$279,467,992
Oregon	18	10	NA
Pennsylvania	131	21	$659,002,980
Puerto Rico	7	1	NA
Rhode Island	13	3	NA
South Carolina	19	3	NA
South Dakota	7	2	$153,257,412
Tennessee	36	6	NA

Texas	116	28	$1,130,694,228
Utah	24	10	NA
Virginia	76	11	$312,926,940
Vermont	5	1	NA
Washington	32	10	$202,553,550
Wisconsin	35	9	$169,200,000
West Virginia	3	2	$530,105,856
Wyoming	6	3	NA

Recently it is reported by National Science Board [9] that the number of science and engineering bachelor's degrees awarded rose steadily from about 400,000 in 2000 to more than 650,000 in 2015. The number of bachelor's degrees awarded in the US is increased relatively consistently in all science and engineering fields during the period of 2000-2015, but the exception was computer science, as shown in Figure 4.

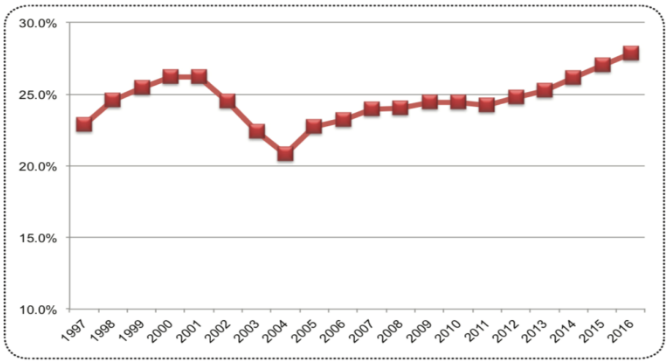


Figure 3: US 20-year Trend in Overall STEM Interest [8].

The released data on college degree output by the National Center for Educations Statistics (NCES) [10], was studied by Economic Modeling Specialists International (EMSI) [11] and found that the STEM degrees rose rapidly from 2009-2010 to 2015-2016 in almost every state of the US as shown in Figure 5. The top five fastest-growing states for STEM majors are New Hampshire (88% growth), Delaware (76%), Utah (66%), West Virginia (62%), and Texas (57%). Nationally, the bachelor's and above STEM degrees has gone from 15% to 21%.

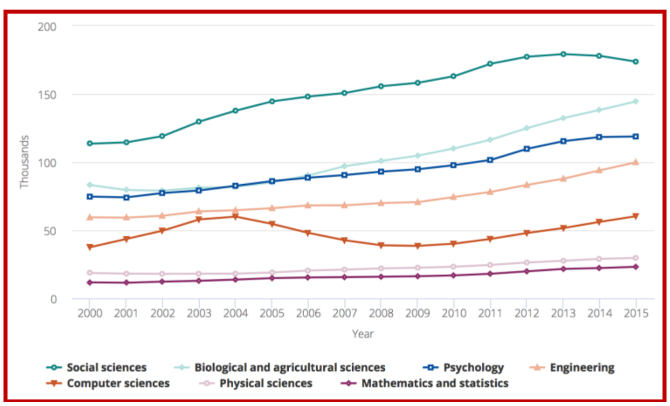
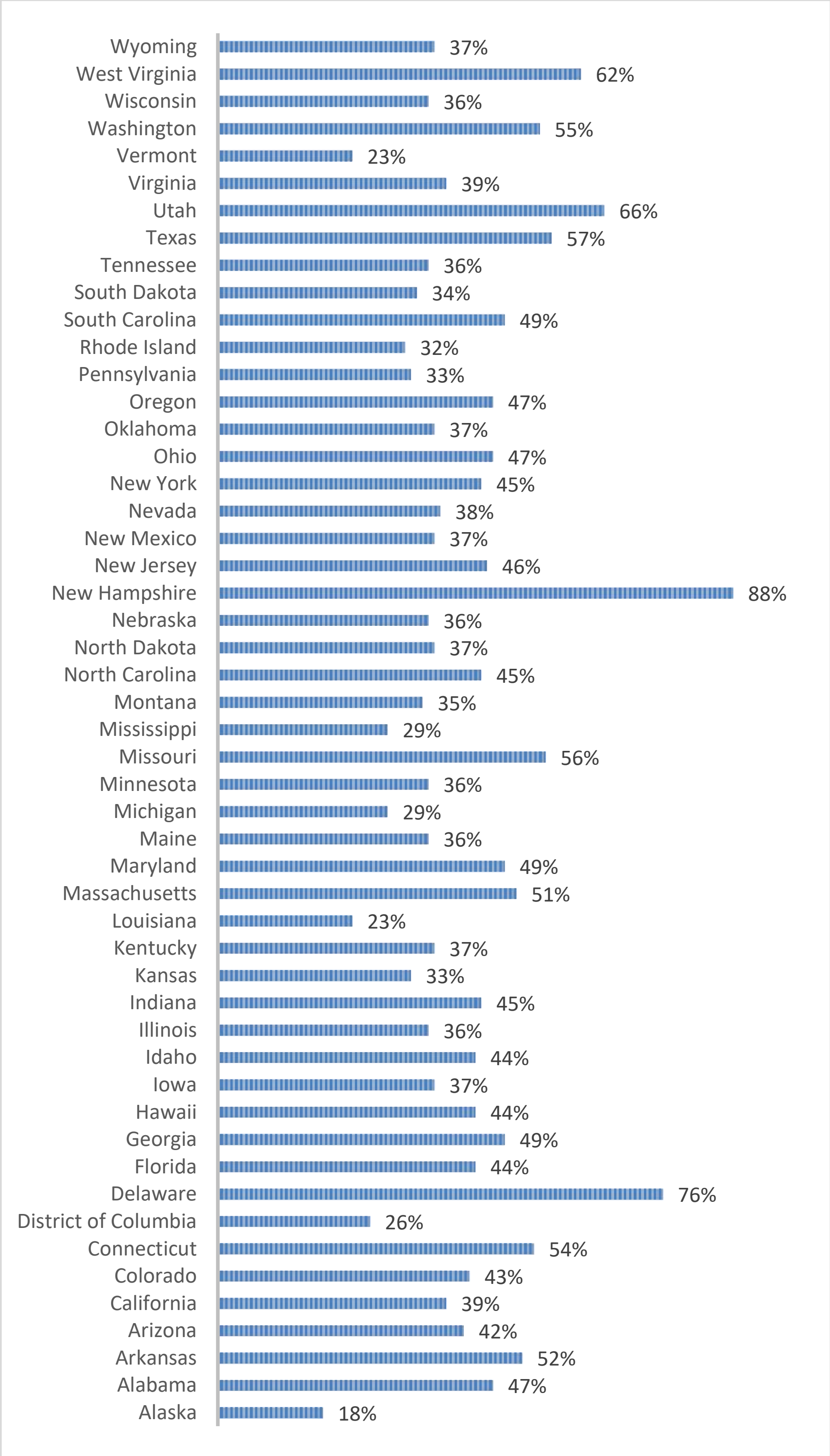


Figure 4: Science and Engineering bachelor's degrees awarded during the period of 2000-2015 [9].

**NA (Not Available) – Active awards amount for some states are not available.



** Growth data not available for Puerto Rico state.

Figure 5: The State-by-state growth of STEM Majors during the period of 2010-2016.

EVALUATION AND OUTCOMES OF THE RET PROGRAM

There are many reports about the success of RET programs all over the US. In this section, we will discuss some of the reports and findings of the success of RET programs.

B. *New Jersey Institute of Technology: The long-term impact of including high school students in an Engineering RET program*

Linda et. al [12] reported the positive impact of the RET program made on the students of the RET-participated teachers for 10 years in the New Jersey Institute of Technology (NJIT), a university in the northeast. Every year 14 high school mathematics and science teachers participated in the RET program of NJIT, and teachers also brought six to eight high school students who worked as partners in research teams with teachers (total 26 students in 9 years). Many of the students continued to be involved in the research projects after the summer. In most cases, the student's summer work helped them to decide on their course of study in college. As reported by NJIT, all of these students are pursuing a career in STEM fields and attending state colleges in the North East, and few of them have gone to big private colleges including NYU, Harvard, Dartmouth and Washington, and Lee. Over the 10 years, one teacher has been invited back each year to participate in the RET program to continue development of engineering curricula for her high school and serve as a mentor for other teachers in the program. She involved her 24 high school students in at least one summer research experience and reported the detailed summary of her 21 students about the colleges they attended, their gender, year(s) attended, and their majors (See Table 3). These are incredibly remarkable accomplishments considering the fact that the high school these students attended is in an urban area with a high-proportion of under-represented and economically-disadvantaged students of which only an average of 51% go on to attend a four-year college after graduation (in any major not necessarily STEM). This study shows successful implementation of the RET program and its positive impact of on the STEM interest and enrollments.

C. *University of Southern California: A seven-year study of middle and high school teachers participating in RET programs*

Ragusa and Juarez [13], reported the results of seven-years (2010-2016) of two RET programs, funded by the NSF, with middle school teachers (3 years) and high school teachers (4 years) and their students. In total, 70 teachers and their 10,398 students participated in these two RET programs.

The results are findings of these two programs are:

- The RET teachers had a mean science teaching efficacy of 3.68, which is significantly higher than the national average of 2.47. The efficiency is measured by the Science Teaching Efficacy Beliefs Instrument-Revised (STEBI-R secondary) tool [14]. The STEBI utilized a Likert scale format. The proposed instrument includes personal science teaching efficacy (PSTE) and science teaching outcome expectation (STOE) which was similar to the anticipated outcomes. Mean scores for RET participants have been compared to non-RET groups.
- The mean score on teacher performance rating was 3.97 which is significantly higher than the state's average rating of 2.89.
- The RET teachers had a significant performance gain in the pre-to-post program.
- The participating teacher's students made significant gains during their curricular intervention resulting from their teacher's participation in the RET programs.
- The students gained science and engineering knowledge and increased their science interest and motivation.

The pre-program and post-program results of the RET program on the student's motivation, interest, and engagement in science are shown in Table 4. These results clearly indicate that the students made statistically significant gains during their curricular intervention resulting from their teacher's participation in the RET programs.

Table 3 [12]: Detailed Summary of College Attendance and Major

Year(s) Attended	Gender	College Attending	Major/degree
2007	Male	NJIT	Biomedical Engineering
2008	Female	Stevens/NYU	Biomedical Engineering
2008-2009	Female	Dartmouth	Pre Med
2009	Male	Rutgers	Science Journalism
2009	Female	Rutgers	Chemistry
2009	Female		Pharmacy
2010	Female	Felician College	Forensics
2010	Male	Rutgers	
2010-2011 2012 REU*	Male	Rutgers Tufts University	Chemistry MD PhD
2011	Male	The College of NJ	Chemistry
2011	Male	Rutgers	
2012	Male	Rutgers	Mechanical Engineering
2012	Male	Washington & Lee	Math/Computer Science
2013	Male	Rutgers	Nursing
2013	Male	Rutgers	Engineering
2013-2014	Male	NJIT	Biology/Pre Med
2014	Male	NJIT	Biology
2014-2015	Female	Rutgers	Neuroscience
2015	Female	Notre Dame	
2015-2016	Female	Still in High School	Graduating 2017
2016	Female	Still in High School	Graduating 2017

*REU – Research Experience for Undergraduates

Table 4: Student Results of RET program (2010-2016)[13]

Metric	Pre-Program % Score	Post-Program % Score	% Gains
Science Knowledge	57.3	92.6	35.3
Science Literacy	51.9	87.3	35.4
Science Interest & Motivation	54.2	89.3	35.1

***D.** Iowa State University (ISU) RET Teacher-Scientist Partnership (TSP) Program: Impact of RET program on high school student's perception of science*

Kevin Schneider [15] evaluated the ISU RET program to explore if there is a change in the perception of science, scientists and science careers for students whose teachers participated in RET programs. The participants in his study were high school students ranging from grades 9-12 from the state of Iowa. Total 149 high school students took the pre-survey, and 66 high school students completed the post-survey. Table 5 shows the study results about the improved science career perceptions. A significant portion of students reported 5-strongly agree for becoming a scientist and pursuing science as a career. The data in this study dismantled the negative attitude about the science careers. This study clearly supports that the RET curriculum helped students increase their positive feelings about science, scientist and a desire to work in a science-related career.

***E.** Texas A&M University: Long-term impact of the Enrichment Experiences in Engineering(E^3) RET Program*

The Enrichment Experiences in Engineering summer teacher program was funded by NSF RET program from 2003 through 2013. This program was hosted by the Dwight Look College of Engineering at Texas A&M University.

Autenrieth et. Al [16] reported findings to assess the long-term impact of the NSF RET funded E^3 program. Total 150 teachers participated in this program, and most of the teachers were from schools with a high percentage of underrepresented minority student's population. The post-program survey result about the teacher's ability to promote engineering to their students and the
postsecondary academic majors discussed with their students are reported in Figure 6 and Figure 7, respectively.

Table 5: RET program survey result for the perception of science careers [15]

*Student proportions for career category questions. Statistically significant shifts from pretest to posttest are highlighted and denoted as **.*

Rating	1-SD	2-D	3-U	4-A	5-SA	Total	Average
I could become a scientist.							
Pre %	15.75**	14.38	23.29	27.40	19.18**	N=146	3.20
Post %	3.03**	13.64	12.12	30.30	40.91**	N=66	3.92
I would consider pursuing science as a career.							
Pre %	16.22**	18.24	25.68	24.32	15.54**	N=148	3.05
Post %	4.55**	13.64	21.21	30.30	30.30**	N=66	3.68
I would attend a summer science camp or research internship.							
Pre %	32.19**	16.44	30.14	12.33	8.90	N=146	2.49
Post %	15.15**	21.21	33.33	13.64	16.67	N=66	2.95

SD (Strongly Disagree); D (Disagree); U (Unsure); A (Agree); SA (Strongly Agree)

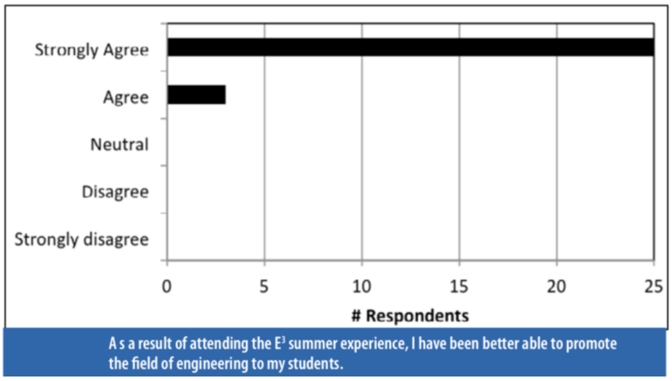


Figure 6: Post-program survey result of teachers to continue to promote STEM to their students [16]

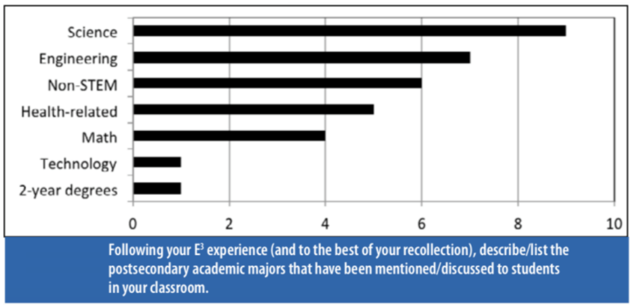


Figure 7: Post-program survey result of teachers about postsecondary academic majors discussed to students [16]

The evaluation findings document that this program has been successful in educating teachers about the science and engineering field and in the long term, teachers continue to promote STEM to their students as a career option.

CONCLUSION

In this paper, we provided a guideline of the process for developing a RET project according to the NSF guidance. We discussed the significant impact of RET on the development of curriculum on successful classroom experiences for both teachers and students. We also provided some statistics on the progress of STEM enrollments throughout the USA. We concluded that the RET program is a benchmark and state of the art research experience which can help school teacher to get a hand experience on R&D experience and can convey this knowledge to their students. To equip the K-12 teachers with scientific discoveries, new technologies, and research led to significant changes in curriculum and teaching standards which increase the student's interest in STEM education. This type of research experience will definitely support teaching at schools and help to produce a better education system that assists both the teacher and the students.

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