AC 2012-5235: THE IMPACT OF BIOMEDICAL ENGINEERING RESEARCH EXPERIENCES ON UNDERGRADUATES UNDERSTANDING OF RESEARCH PRACTICES AND CAREER TRAJECTORIES

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The Impact of Biomedical Engineering Research Experiences on Undergraduate Understanding of Research Practices and Career Trajectories

Abstract

The National Science Foundation and many other institutions support undergraduate research with an expected outcome of broadening participation in careers in science and engineering. Since 2008, the Illinois Institute of Technology has offered approximately 40 students from across the U.S the opportunity to participate in a summer Biomedical Engineering Research Experience for Undergraduates (REU) program. The goal of this program is to immerse undergraduates in biomedical engineering laboratories to conduct cutting-edge diabetes research in an effort to influence their long-term interests in science and engineering. The program is also intended to inform the undergraduate students' understandings about research design and practice. In this study, the program's influence on these types of understandings and its potential impact on their career choices was explored. Pre- and post-Likert and open-ended survey items were coupled with a content test and semi-structured interviews to examine the extent to which the program goals were met. Data analysis of the pre- and post-survey items that focused on career and research topics related to the program goals were on average above 4 on a 5-point Likert scale suggesting that the students had high expectations of the program initially and that these expectations were met upon program completion. Additional findings related to how the program influenced the participants fell into three main categories: understandings about the process of research development and practice, career and graduate school decisions, and role of the laboratory personnel. The implications of these findings include a framework that might directly inform the revision and improvement of REU programs that aim to influence the retention of participants in STEM careers. In addition, REU programs also have the potential to

engender undergraduate students' informed conceptions of science and engineering research design and practice early on in their career trajectories.

1.0 Introduction

Undergraduate research experiences are anticipated to both increase understanding of research practice and motivate students to pursue advanced degrees in the sciences and engineering.[1] Broadening participation in careers in science and engineering is often a primary goal of these programs and the government funding associated with them. However, the ability to reach students at critical transition points in their career trajectory is difficult.[2,3] Undergraduate research is often primarily performed by students who have already established clear career goals,[2] and the experience either confirms the students' plans or strengthens their resumes.

Research experience is also expected to enhance undergraduates' understanding of research, increasing both their general knowledge of research careers and their ability to design and perform research. While even in the most poorly designed research experience this may occur to some extent, the optimal method for delivery and preparation of students for sound research in engineering and science is not clear. Many research experiences are 8 to 10 week summer programs. Within these relatively short time frames the programs should carefully consider organization and structure in order to maximize impact. However, our knowledge on how to best deliver research training is incomplete.

The impact of experience in a research lab is likely to depend on a number of program factors: organization, nature of interactions with the mentoring team and the level of student interest in the project.[3] Over the past 6 years we have run a summer undergraduate research program that has focused on engineering research in diabetes, including both treatment and understanding of the disease and its complications. Student projects and activities are focused around the disease. Diabetes has a significant societal, and often personal, impact and has the potential to increase the students' long-term interests in science and engineering research. Another primary goal is to inform the undergraduate students' understandings about research design and practice. In this paper, our assessment of the program and its influence on the students' understandings of research and its potential impact on their career choices was explored.

2.0 Methods

2.1 Program

From 2006-2011, 10-15 students participated annually in this program. Students were paired with research mentors based on project rankings, student background, academic level and experience. Over the ten-week program, students were expected to complete a challenging research project focused on engineering approaches to the study and treatment of diabetes or its complications.

Participating faculty mentors were from a variety of departments, including Biomedical Engineering, Chemical Engineering, Biology, Chemistry, and the School of Medicine. Diabetes is a complex pathologic condition and addressing the disease requires a diverse set of approaches from fundamental understanding of disease pathology, disease management and treatment either of the disease directly or one of its many complications. The students joined projects related to diabetes that were developed from ongoing work in the faculty laboratories. Research projects in this REU program reflect this diversity, with projects offered in metabolic engineering, biomaterials, biosensors, and tissue engineering. Sample projects from the 6 years are shown in Table 1.

Table 1 Sample Projects from the REU program

Project	**Relationship to Diabetes**
Role of Hemorheological Parameters and ADMA in End Stage Renal Disease and Chronic Renal Disease Patients	Understanding of a complication
Effects of Diabetes on Brain Tissue Volumes using Postmortem MRI	Identification of new complications
Sustained Delivery of Anti-VEGF Therapeutics to Treat Diabetic Retinopathy	Treatment of a complication
Glycation (of collagen I rich tissues) affects enzymatic activity	Mechanism underlying complications
Design of Alginate Microbeads for Islet Encapsulation	Treatment of the disease
oodFit, a newly designed web application to illustrate food and physical activity choices	Monitoring the disease
Biomaterials for Wound Healing Applications	Treatment of complications
Ca2+ oscillations in Islets of Langerhans and a novel approach to modeling	Fundamental understanding of biological mechanisms
Quantitative Analysis of Optical Glucose Biosensor by the System of Catalytic Enlargement of Gold Nanoparticles via Redox Enzyme	Technique for disease evaluation
Imaging Islet Development	Mechanism underlying the disease

In addition to research, students participated in weekly seminars on topics related to diabetes (basic research, clinical treatment public health and policy), weekly ethics seminars, and tours of clinical facilities. These activities were designed to expose students to the broad health implications of the disease and the importance of research related to the treatment and potential cures for this disease.

2.2 Assessment

Program assessment has been conducted on an annual basis since the program's inception through pre- and post-program surveys and content tests. These evaluation tools are intended to illustrate the extent to which program goals are met and to illuminate any areas of potential concern. The pre- and post-program surveys collected student demographic information and consisted of both open-ended and Likert scale items. Education background, career aspirations, family education, and lab experience were the four topic areas covered in the open-ended items. A sample item of each topic area, respectively, includes: What science courses did you take during high school?; What careers are you interested in pursuing?; Did anyone in your immediate or extended family pursue a science or engineering career?; What role do you expect the advisor to play/did the advisor play during the undergraduate research experience?. The full surveys can be found in the authors' previous work from our group.[4]

There were six topic areas covered in the 5-point Likert scale portion of the survey, with 11 – 20 items per topic area. The Likert scale items provide insight into the impact of the research experience on the participants' research interests, discipline understanding, practical research skills, understanding about the practice of research, attitudes about science- and engineering-related research, and attitudes about graduate school and careers in the science and engineering fields. Samples of Likert scale items on attitudes about careers include: "To what extent do you anticipate/did your undergraduate research experience affect your attitude in your, "Ability to work in a community of scientists?"; "Confidence in your ability to contribute to science?"; and, "Confidence in your ability to present/defend research?".

Participants are also asked to complete a pre- and post- content test that covered two topic areas: scientific/engineering methods and experimental design and basic knowledge about diabetes. This assessment provides insight into the growth of participants in areas directly related to their research experience. These areas include knowledge about specific aspects of research design such as the role of a control, appropriate sources of reference materials, and the similarities and differences between science and engineering. A sample item related to experimental design is: “Explain and provide an example of the differences between a hypothesis, an objective, and an assumption.” The basic knowledge about diabetes covered includes the difference between Type I and Type II, treatment options, and long-term side effects of the disease. A sample item administered to measure students’ understanding of diabetes, includes: “What treatment modalities exist for diabetes (differentiate between Type 1 and Type II)?”. A subset of items from the content test is in Appendix C.

After completion of the 2011 program year, a systematic evaluation of data from the previous three years was undertaken to assess the program’s impact on participant perceptions about science and engineering, their graduate school decisions relevant to the REU and their understandings about science and engineering practices. This evaluation expanded the assessments to include interviews with a sample of undergraduate student, graduate student, and faculty member participants. The interviews were developed to further understand the program outcomes as well as to support the validity of the surveys and content tests. Twenty student participants, 22 graduate students, and 13 faculty members from the 2009, 2010 and 2011 program years were invited to provide feedback during a phone interview with the first two authors. Three samples of undergraduate semi-structured interview items, include: “What were your expectations of the program?”; “How did the program influence your academic and career choices?”; and, “How did the program influence your conceptions of science and engineering? Three samples of graduate student and faculty semi-structured interview items, include: “Describe your involvement in the program.”; “How did you influence the students’ academic and career choices?” and, “How did you influence the students’ conceptions of science and engineering?”. The complete undergraduate student and graduate student/faculty member interview protocols can be found in Appendices A and B.

3.0 Results and Discussion

3.1 Program Demographics

In six years of this REU program, 64 undergraduate students have been supported through funding from the National Science Foundation. These students are from 24 different states and 46 institutions (Figure 1). Based on the United States Census Bureau definition of geographic regions 54% of the students were from the Midwest, 17% from the Northeast, 17% from the South, and 11% from the West. Participation by the Midwest was high, with a significant number of students (30%) were from institutions within the state of Illinois. Additional students from the host institution were supported through other mechanisms.

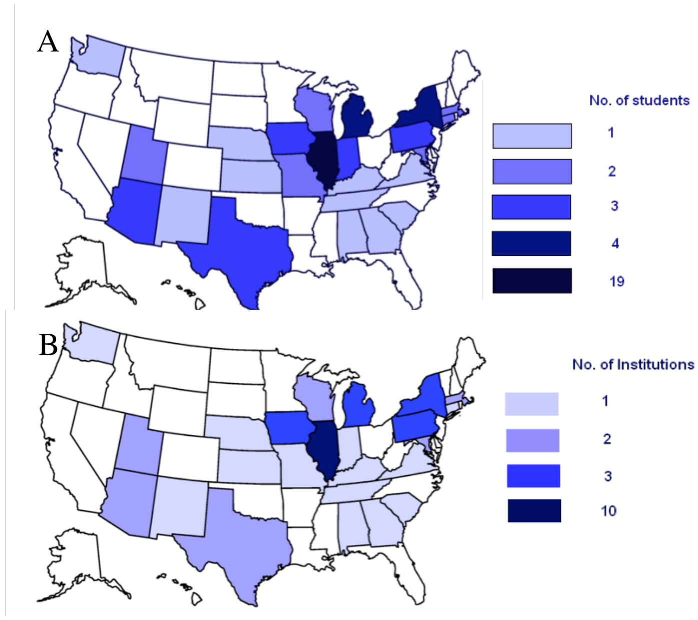

Figure 1: Demographics from 2006-2011 with (A) number of students and (B) number of institutions from each state participating.

This program specifically targets three student populations: 1) women, 2) underrepresented groups, and 3) students without previous research experience.

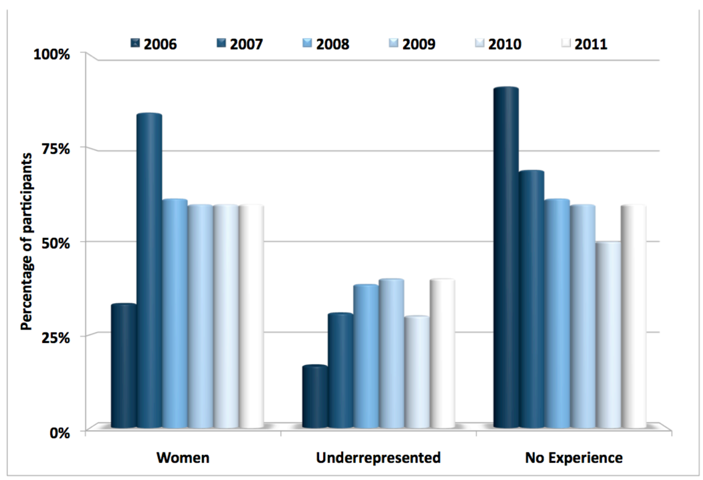

Figure 2: Percent of REU students that were from targeted populations from 2006-2011.

Acceptance into the summer is not limited to students from these populations. Over the 6 years participation was 60% women, 32% underrepresented groups, and 66% students without previous research experience. In 2006 the percentage of women participating was relatively low (33%, Figure 2) but was greater than 50% in all subsequent years. The percentage of students from underrepresented groups was 17% in 2005 and between 30 and 40% from 2007-2011. In addition 4 students were type I diabetics and one was a veteran. There was been a gradual decrease in the number of students without previous research experience to 50% in 2010. However, in 2011 60% of students did not have research experience.

3.2 Analysis

Pre- and post-surveys, pre- and post-content tests, and post-student interview data were analyzed to gain insight into how the program influenced the undergraduate students. Post-interviews with the graduate students and faculty members were analyzed to understand their roles in the program and how they perceived their influence on the undergraduate students' experiences in the program. Descriptive statistics were used to analyze the 5-point Likert scale items of the pre- and post-surveys. A constant comparative method[5] was used to analyze the open-ended items of the survey, content test, and interview protocols. The first two authors independently coded data sets to create initial code dictionaries. Meetings were scheduled to share, interpret, and consolidate codes. The development of codes was negotiated until agreement in order to establish inter-rater reliability of the analysis method. The codes that emerged were grouped into six main categories: experimental knowledge, research preparation and design knowledge, career focused preparation, engineering versus science, science content knowledge, and the role of laboratory personnel.

Given the focus of the program on participant understanding of diabetes research and its efforts toward supporting and developing the interests of undergraduates in pursuing science and engineering related programs of study in graduate school, those items on the pre- and post-assessments relevant to those aims were emphasized. The validity of findings is supported by their triangulation across multiple assessments and only those items and categories that were assessed within at least three assessments inform findings. Validity was established with three of the six categories: research preparation and design knowledge, career focused preparation, and the role of laboratory personnel. The other three categories, experimental knowledge, engineering versus science, and science content knowledge, were found not to be valid and will not be further discussed. Table 2 below describes the three valid categories and the two corresponding assessments used in the analysis.

Table 2 Assessment matrix for category development

Categories of Outcome Data	**Assessment 1**	**Assessment 2**	**Assessment 3**
1) Research Preparation and Design Knowledge	Student Survey Items: 29, 30, 40, 41, 42, 48, 51, 52, 53	Student Content Test Items: 4, 5, 6	Graduate/Faculty Interview Item: 8c
2) Career Focused Preparation	Student Survey Items: 61, 75, 81	Student Interview Items: 2a, 2b	Graduate/Faculty Interview Items: 6
3) Role of Laboratory Personnel (ie. faculty and graduate student)	Student Survey Items, 49, 50, 55, 56, 68, 73	Student Interview Items: 3a, 3b, 4a, 4b, 7a, 7b, 8a, 8b, 10a, 10b, 13a, 13b, 14a, 14b	Graduate/Faculty Interview Items: 1, 5a, 5b, 7a, 7b, 9a, 9b, 10

3.3 Findings

REU Undergraduate Student Participant

The average Likert ratings on the survey items above for the Research Preparation and Design Knowledge category were 4.04 on the pre-survey and 3.86 on the post. Similarly on the

Career Focus Preparation category and the Role of Laboratory Personnel category, the average ratings on both the pre and post- assessments were approximately 4 out of 5. This suggests that student expectations for their participation, relative to these three categories, were high upon entering the experience. Based on the similar scores upon exit, those expectations were met. The nuances of their perceptions, however, were of interest during the evaluation and the interview and content test data provided insight into their nature.

The Research Preparation and Design Knowledge category was informed by nine Likert survey items and three open-ended items on the content test (Appendix C). Two of the three items on the content test explored students' understanding of the preparation phases of research. On both of these items, students' responses demonstrated understanding on the pre-test and therefore participants had already mastered this specific understanding prior to participation. The third item demonstrated similar understanding on the pre-test but some changes were evident on the post-participation administration. After program completion, responses were increasingly grounded in descriptions of a more practical nature, some of which were suggestive of developing misperceptions about science. For example, four participants noted in their post-test that engineering research is informed by empirical data and mathematics to a greater extent than is science. While these types of perceptions were not expressed on the pre-tests, their mention on post-tests suggests that these participants had become increasingly familiar with the practice of research and needed more explicit discussion in the program about the commonalities of research despite some of the differences in science and engineering contexts. The comparison between science and engineering was not an explicit program goal and as such was not emphasized throughout the experience.

The Career Focused Preparation category was explored both through survey and interview items. The three Likert items were similarly positive in both their pre and post-assessment. The interviews were used to illuminate the nature of their influence given the positive trend. Six REU student participants agreed to take part in the interviews conducted and transcribed by the second author. Each respondent was either still pursuing their undergraduate degree or was enrolled in a graduate program in a science or engineering field. All six participants stated that the REU experience supported their interest in pursuing a STEM graduate degree and that the research experience provided them with some direction for future work as illustrated by the following response. *"[The program] definitely [supported interest]. This was actually my first experience in any lab. I was definitely looking for something in the summer that was related to my major that could kind of give me an idea of what one area of research was like."* Each participant described nuanced ways in which it influenced their career goals, but all participants general sentiments are described by the following statement from one participant, *"It reaffirmed my goal of wanting to go into a science field."* In one case, the graduate area pursued was related to the technology he worked with in the research lab and not with the research area itself.

The third category of interest was related to the roles of the laboratory personnel, primarily graduate student, who were involved in the program. It was within this category that there was some significant variation among responses. As mentioned, the pre- and post-survey ratings were approximately 4 and the interview responses were positive with regard to the value of their laboratory supervisors. All six of the participants described very limited interactions with the participating faculty member and primary supervision by a graduate student. In three cases, that graduate student was a staple in the lab setting and a single person took responsibility for their training and participation. *"While I was doing my work I had a grad student that just worked directly with me. So if I had questions she could answer my questions. If not, we could sit there and look it up and I think it was very collaborative."* In each case, the student participant had a positive experience working relatively closely with them. The remaining three participants described a more isolated experience in which they were trained and directed by a number of alternating individuals. *"There were three to four grad students in there filtering in and out. Some went on vacation for a couple of weeks throughout the summer. Most of the time though there were at least two, usually two or three in there."* In part, due to the timing of the REU during the summer months, many lab staff took time off. Even in these cases, however, the participants emphasized the positive experience of working in the lab and guidance with regard to the research they received.

REU Graduate Students

Five REU graduate students agreed to take part in the interviews conducted and transcribed by the first author. The purpose of the post-interview was to gain a more in-depth understanding of their role and their perceived influence on the undergraduate students' experiences in the program. Five items from the graduate/faculty interview protocol explored the Role of the Laboratory Personnel category. The graduate students interacted with the undergraduate students on a daily basis throughout the 10-week program. The graduate students described being mentors and advisors to the students. Most of the undergraduate students did not have prior laboratory experiences; therefore, the graduate assistants introduced the students to the operations and culture of the laboratory. The graduate assistants supported the undergraduate students through each stage of their research project. The graduate assistants trained and guided participants through the project, and helped them prepare project presentations. Specifically, the graduate assistants were responsible to train students on how to properly use the laboratory equipment and conduct procedures for the research project. Answering the students' questions and guiding the students' thinking, throughout the program, was another key role the graduate students described doing in their interviews. As evidence, this is how a graduate research assistant described his role in the program, *"I tried to act like his advisor through the 10 weeks. Any questions that he had I tried to be like his mentor. I see myself as a teacher so I liked getting this mentor experience. This role made me feel more confident in what I want to do because [the undergraduate student] would ask me questions and I would have to give him the answer versus me being the one asking the questions. So it was definitely at a challenge at first taking on this role but in the end it gave me a confidence boost."*

The graduate students described multiple ways that they influenced the undergraduate students' understanding of research preparation and design knowledge. One interview protocol item explored the Research Preparation and Design Knowledge category from the graduate research assistant perspective. Early on in the program, the graduate assistants provided the students with basic background information on diabetes and pointed out the connections to the research of the laboratory. The graduate students observed the undergraduate students develop an understanding of the science and how it directly applied to their own research project. This was evident in the types of questions, exchange of ideas, and discussions the graduate students had with the undergraduate students, along with, the quality of their research project presentations. In addition, the graduate students described the development of the undergraduate students' laboratory skills and essential ability to multitask in the laboratory setting. As the program progressed, the graduate students felt the undergraduate students' had adapted to the laboratory environment and were able to work more independently. As evidence of the graduate students influencing the students understanding of research preparation and design, *"Prior to the program, [the undergraduate student] did not have any laboratory experience. The first two to three weeks I was eagle eye over [the undergraduate student] making sure he was doing things correct. By the second half of the summer he was pretty much by himself. [The undergraduate student] knew where everything was and what to do. So in a matter of a few weeks he was able to advance."*

The graduate students described experiences with the undergraduate students that were directly related to the career focused preparation. One interview protocol item explored the Career Focused Preparation category from the graduate research assistant perspective. The graduate assistants described how the design of the program was similar to graduate school and the work setting and the potential influence it had on the students academic and career decision-making. In the interviews, the graduate students described initiating discussions with the undergraduate students about their future academic and career paths. The undergraduate students interest and engagement levels in these discussions varied, according to the interview data. For some students, it was too early for them to discuss specific career paths with the graduate assistants because they were more focused on completing their science coursework. Though, for other students, the graduate assistants described having meaningful discussions with the students about how the program solidified their decisions to pursue research careers.

REU Faculty Members

Five REU faculty members agreed to take part in the interviews conducted and transcribed by the first author. Like with the graduate students, the purpose of the post-interview with the faculty was to gain a more in-depth understanding of their role their perceived influence on the undergraduate students' experiences in the program. The same interview protocol items were administered to the graduate students and faculty members; thus, the same items informed the three main categories as mentioned in the previous section. Based on the interview data, the main role of the faculty member was to provide the opportunity, resources, and laboratory setting for the undergraduate students. Each faculty member paired the undergraduate student with a graduate research assistant working in their laboratory. The faculty members described their interactions with the undergraduate students to be more indirect and peripheral. They tended to have more direct contact hours with the graduate research assistant who was paired with the undergraduate to receive and discuss updates on how the undergraduate student and their research. Providing this opportunity to their graduate students was an approach to prepare them to be future faculty advisors.

The faculty members influenced the undergraduate students' career focused preparation and research design and preparation knowledge by providing them with the resources to develop and take ownership of a research project. As evidence of the faculty members influencing the students' career focused preparation, *"This program is a checkpoint for the students, to make the decision about their career paths. I think we have been very successful at getting undergraduates to become interested in engineering research and many have gone on to graduate school. About 80% of my students have gone on to graduate school and many will eventually move on to either an academic or industry research career."* Furthermore, the faculty described how the learning environment of the laboratory was different than what the students typically experienced in college. As evidence of this finding, *"For the most part, this is the first time the students are gaining research experience. It is critical for them to know the expectations of research work* *and understand how it is very different than their typical college experience. This experience is not about turning in homework on time or getting an A in a course. My research lab environment both for my graduate and undergraduate students is a free-willing environment. There is a graduate student assigned to the undergraduate student and becomes their day to day go to person in the lab but the students have access to everybody. Once this is established in the environment they do it and they just deliver. On a weekly basis I meet with both the undergraduate and graduate students to assess their performance and progress. We discuss what work needs to be done the follow week and identify key milestones for the delivery of project*." Overall, the faculty members described influencing the undergraduate students by providing them with the opportunity to experience firsthand the life of a scientist and the responsibilities of the science workforce.

3.4 Conclusions and Implications

The analysis ultimately suggests that the program does positively impact student participants in three distinct areas. First, participant understandings about research practice showed that student expectations for growth in understanding were met. Their high expectations in this category were satisfied given the ratings on the post-administration of the survey. The understandings that they demonstrated on the content test also suggest a pattern of growth although some emerging misconceptions about differences between science and engineering research contexts were evident. The interviews further supported the claim that the program positively impacted their understanding of research practice and students emphasized the program's value in this capacity.

Secondly, the program's influence on participants' career trajectories was also found to be positive. Again, the pre and post-survey data suggested that students entered the program with high expectations and the sustained high ratings indicate that those expectations were met. The interviews with both undergraduate and graduate students support the assertion that there was an influence on science and engineering career trajectories. Undergraduate student participants cited the value of the program as an experience that better prepared them for the work of graduate programs and also for raising their awareness of biomedical engineering-related careers and graduate programs of study.

The third category of interest was the nature of the role of the graduate research assistant and faculty members. The survey data suggested a positive trend with regard to the availability and helpfulness of the graduate student. The interviews with both the undergraduate participants and the graduate students illustrated more variability among the participating labs. The value of the graduate students was not disputed, but the variation in the extent of their involvement with the undergraduates suggests that some additional guidance with respect to their role may be valuable.

Although the students were engaging in diabetes related research, their understanding about research in general, and science and engineering careers in general was found to improve. With regard to the role of faculty and graduate student assistants, the relationship between the undergraduate and graduate student participants was also found to be influential. The emphasis on diabetes research makes this program unique among REU experiences, but it was found to positively influence students' understandings about research practice and science and engineering career paths independent of context.

4.0 Acknowledgements

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Appendix A

REU Undergraduate Student Interview Protocol

1) What are you doing now?

2a) How did the program influence your academic? 2b) Career choices?

3a) How did the graduate students influence your academic and career choices? 3b)Provide an example of an interaction/experience with the graduate student during the program.

4a) How did the faculty influence your academic and career choices? 4b) Provide an example of an interaction/experience with the faculty during the program.

5) What expectations/motivations did you have going into the program?

6) What were the outcomes of participating in the program in relation to the previous question?

7a) How did the graduate students influence these outcomes? 7b) Provide an example of an interaction/experience with the graduate student during the program.

8a) How did the faculty influence these outcomes? 8b) Provide an example of an interaction/experience with the faculty during the program.

9a) How did the program influence your conceptions of science? 9b) Engineering? 9c) Science research design and practice?

10a) How did the graduate students influence your conceptions? 10b) Provide an example of an interaction/experience with the graduate student during the program.

11a) How did the faculty influence your conceptions? 11b) Provide an example of an interaction/experience with the faculty during the program.

12) To what extent did you participate?

13) Can you clarify x? y?

14a) To want extent did the graduate students participate? 14b) Describe your overall experience with the grad students.

15a) To want extent did the faculty participate? 15b) Describe your overall experience with the faculty.

16) Other things we should know?

Appendix B

REU Graduate Student/Faculty Member Interview Protocol

1) Describe your involvement in the program.

2) Why did you decide to become involved in the program?

3) What were the goals of the program?

4) What were the outcomes of the program in relation to the previous question?

5a) How did you influence these outcomes? 5b)Provide an example of an interaction/experience with the student during the program.

6a) How was the program designed to influence the students' academic choices? 6b) Career choices?

7a) How did you influence the students academic and career choices? 7b) Provide an example of an interaction/experience with the student during the program.

8a) How was the program designed to influence the students' conceptions of science? 8b) Engineering? 8c) Science research design and practice?

9a) How did you influence the students' conceptions? 9b) Provide an example of an interaction/experience with the student during the program.

10) To what extent did you participate in the program?

11) Can you clarify x? y?

12) Do you plan on participating in the program or similar program again in the future?

13) Other things we should know?

Appendix C

Subset of items from content test

4. What is the very first step to beginning a research project?

   a. Plan the experiments
   b. Review the literature to determine what else has been done
   c. Formulate the hypothesis
   d. Determine expected results
   e. Determine possible experimental problems that may arise

Explain the reasons for your choice:

5. What are appropriate sources to review previous work performed in a particular research area?

   a. The internet
   b. Textbooks
   c. Journal articles
   d. Newspapers/magazines
   e. Conference Proceedings/abstracts

Defend your decision

6. Explain the similarities and differences between engineering and science. Give 2 similarities and 2 differences.