AC 2008-932: THE INFLUENCE OF A HANDS-ON RESEARCH EXPERIENCE ON UNDERGRADUATE STUDENT PERCEPTIONS OF ENGINEERING RESEARCH

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The influence of a hands-on research experience on undergraduate student perceptions of engineering research

Abstract

Results of a multi-method study of both a national pool of applicants and nine participants selected for an eight-week summer research program in a university mechanical engineering department are the focus of this paper. Funded by the National Science Foundation through a Research Experiences for Undergraduates (REU) Site grant, the program paired undergraduate engineering students with professors engaged in experimental research during the summer of 2007. Students were competitively selected from a pool of nationwide applicants, and nine participants were chosen. Students participated in research focused on experimental methods in mechanical engineering, ranging from bone mechanics to laser micro-machining to fluid dynamics. The program also featured a variety of activities including weekly seminars on experimental methods, field trips to local engineering companies, and a poster presentation at the conclusion of the program.

A survey of 14 REU program applicants provided academic and career interest profiles, including high school activities, origins of their choice of engineering as a college major, the perceived benefits of an REU program, and ethnic diversity. The applicant survey also allowed feedback regarding the effectiveness of promotional materials used by the host institution, and how students learned of the REU opportunity. Results of before-program and after-program paper and pencil surveys and moderator-led focus groups among the nine REU participants are also discussed. The surveys and focus groups addressed program outcome issues such as perceptions of engineering research and desire to pursue graduate studies, liked most and liked least aspects of the REU experience, and ways the program could be improved. Contrary to expectations, the REU experience resulted in some participants deciding against enrolling in graduate engineering school or pursuing careers in engineering research. Results will be used to inform both programmatic and promotional decisions for the planned 2008 and 2009 site programs. The paper will also discuss additional implications of an REU program for faculty who plan to apply for similar NSF grants as well as those who plan to promote such programs to their students.

Introduction

A National Science Foundation (NSF) funded Research Experiences for Undergraduates (REU) Site was conducted during the summer of 2007 at Southern Methodist University (SMU). The theme of the program was "Experimental Methods in Mechanical Engineering," and was chosen due to the large percentage of faculty working in various aspects of experimental research. The theme of experimental methods is also attractive since hands-on research is recognized as an effective method of retention.[1,2] Engineering students also tend to be "active learners", meaning that they learn more effectively from participating in an activity rather than listening to a lecture.[3] Undergraduate research also is a recognized method encouraging students to pursue graduate studies.[4] Research laboratories that participated in the program were the

Laser Micromachining Laboratory, the Experimental Fluid Mechanics Laboratory, the Research Center for Advanced Manufacturing, the Laboratory for Micro- and Nano-Mechanics of Materials, the Laboratory for Porous Media Applications, and the Thermal-Fluids Laboratory.

Several methods were used to advertise the REU program to potential applicants. The first was the development of a website to serve as a central source of information for all interested applicants. The website included program location and dates, student stipend, housing and dining information, a list of participating laboratories and projects, required application forms, and optional survey forms. An email promotional message was then developed which provided basic information about the REU program and referred interested parties to the website for detailed information. The email message was distributed to all undergraduate engineering students at the host institution, to department chairs at other colleges and universities who had previously agreed to help promote the program, and the Women in Engineering Program Advocates Network (WEPAN) list-serve. The WEPAN list-serve allowed for nationwide dissemination of the REU program announcement.

Nine participants were selected from the applicants based on their qualifications, interest in performing research, and choice of research topics. Minimum eligibility requirements for the program were sophomore standing or higher, 3.0 GPA, and a major in engineering or engineering science. Closely related majors in the sciences, such as materials science, physics and chemistry, were also considered if the major closely matched a project for which the applicant was interested. The required application materials included a standard form (contact information, college/university, academic major(s)/minors(s), GPA), transcript, résumé, essay discussing their interests in the REU program, and their choice of projects. All applicants were requested to list two projects and rank them according to preference. Projects representative of the work performed in each participating laboratory were included on the website. Matching of selected participants with faculty mentors was performed by the principal investigators (PIs) based on project preferences.

The program lasted eight weeks during the summer of 2007. Since the students were matched with various laboratories and were not all working with the same research group, the PIs felt that it was important to maintain a cohort experience among the participants. Several group activities outside of the laboratory were organized to facilitate this endeavor. The primary activity was a seminar series on various aspects of experimental methods, taught by the PIs. The titles of the seminars and a brief description of each are listed in Table 1. Group trips to local companies that employ mechanical engineers in design, manufacturing, or research were also organized. A social event over the Independence Day holiday and living quarters located in the same building were also used to enhance the cohort experience.

At the conclusion of the program the students were required to participate in a poster presentation competition. This allowed the students to demonstrate what they had learned during their research experience in the laboratory, utilize the presentation and experimental skills obtained in the seminar series, and observe what other participants worked on during the program. The poster presentations were also open to faculty and staff in the school of engineering. Three judges were chosen from the faculty and staff who were not participating as mentors. Posters were judged on formatting, abstract, motivation, diagram of experimental

apparatus, key results and data presentation, significance of results and conclusions, and oral presentation style. The titles of the student projects were: *Evaluation of Multiple-Interrogation-Window-Size Processing on Relative Error of Artificial DPIV Images*; *Laser Micromachining of Hydroxyapatite*; *Silver Deposition by Laser Induced Forward Transfer (LIFT)*; *Mitigation of Tin Whisker Growth by Composite Tin Plating with Nickel Nanoparticles*; *Laser Welding of Advanced Lightweight Steels*; *Determination of Free Convection Heat Transfer Coefficient from Heat Sinks using Transient Technique*; *Correlation of Mechanical and Ultrasound Testing of Bone*; *Development of a Ball Indentation Technique for Mechanical Property Characterization of Soft Tissues*; and *Particle Flow Rate Control in a PCM Enhanced Capillary Heat Exchanger*.

Table 1: REU Seminars on Experimental Methods in Mechanical Engineering

Seminar Title	**Description**
The Purpose of Measurements	Overview of the types of experiments and their purpose
Uncertainty in Experiments	Uncertainty and error in experiments and how to minimize and quantify uncertainty
Avoiding Mistakes	Proper planning of experiments, sensor response
Written Presentation of Results	Presenting data in graphical and written form; formatting and content for reports, journal articles, etc.
Oral Presentation of Results	Poster presentations, conference and meeting presentations, presentation techniques and time management

Evaluation Method

Two sets of data are reported in this study. One resulted from an applicant profile questionnaire completed by applicants to the REU program. Twenty-nine completed applications were received, and 14 students agreed to complete the applicant profile questionnaire. Questions included demographic profile items, origins of interest in engineering as a field of study or work, how applicants became aware of the REU program, specific questions they had about REU activities, and level of agreement with a series of statements about the field of engineering.

The other data reported in this study were collected from students who were selected for the REU program. The nine REU student participants were asked to complete on-campus First Day and Final Day paper-and-pencil questionnaires, as well as participate in focus group sessions held on their first and last days. All nine students took part in the First Day measures, and eight agreed to share their evaluations and opinions at the end of Final Day.

Both the on-site questionnaires and the focus group discussion guides included items involving program outcomes, perceptions of engineering research, desire to pursue graduate studies in engineering, and evaluation of the REU experience. Question types included dichotomous, multiple response, agree/disagree 5-point scales for directional statements, and open-ended items. Information obtained in the focus groups is used to explain some of the student motivations and recommendations.

Applicant Profile

A total of 10 males and 4 females responded, one of whom was an ethnic minority and one an international student. Ten applicants were from the metro area in which the program was located. The ages of applicants ranged from 18-36, with the median age of 20. At the conclusion of the spring 2007 semester, 4 were rising sophomores, 5 were rising juniors and 5 were rising seniors. The applicants activity background in high school included science fair (n=6), band or orchestra (n=5), and talented/gifted courses (n=4).

Applicant Interest in Engineering

Eleven applicants decided on majoring in engineering during high school. Family members were more likely to have influenced the decision to study engineering than were teachers or counselors. Only one applicant mentioned the influence of a high school counselor in their decision to pursue engineering in college. 12 of the 14 applicants said they were interested in pursuing graduate studies in engineering, and 13 of 14 said they were interested in engineering research.

Applicant Interest in the REU Program

Faculty members at the applicants' institution were the primary source of initial information about the REU opportunity. Applicants indicated that the most common reasons for applying for the REU program were to obtain research experience (n=8) and to obtain hand-on/work experience (n=6). Applicants reported having questions about specific details of the REU program including housing; job contacts/internship opportunities; ability to participate for more than the summer term; ratio of students to faculty; work schedule; and whether there would be an introductory session.

Participant First Day and Final Day Surveys and Focus Groups

An open-ended item that read "Specifically, what do you plan to learn or be able to do as the result of the REU program" was asked on the First Day, and a similar question that read "Specifically, what did you learn or now are able to do as the result of the REU program" was asked on the Final Day. Verbatim responses, included in Table 2, indicate that students anticipated that REU would provide a practical, hands-on experience, and that the focus of their learning would be on the technical or "how-to" aspects of engineering research activities. A reading of the Final Day responses, on the other hand, reveals the basic technical training theme, but also includes the matter of learning how to deal with the uncertainty and potential frustrations that research scenarios present.

Focus groups were used as another means to evaluate the program, since this provides information that is difficult to extract from standard questionnaires. Focus groups provide a relaxed atmosphere in which students can interact, discuss their experiences, and provide qualitative feedback.[5] Focus groups were administered by a co-author (A. Kendrick) who was not one of the research mentors for the students. Results of focus group discussions yielded

similar themes as the surveys. First Day focus group responses to "What would you like to get out of the REU program?" focused on the opportunity to test skills and apply knowledge in a research setting, engagement in activities beyond textbook and classroom studies, and exposure to career options and future job contacts. Final Day responses to "What did you get out of the REU program?" touched on issues ranging from developing patience and time management, having responsibility for important projects and equipment, the daily reality of working individually or in groups for extended periods, and the tedious nature of research. "You had to be self-motivated," said one student, and another commented "I didn't expect them to trust me with tools as early as they did, with maybe 30 minutes of training on one of the robots." "Working on a small aspect of a really large problem is frustrating to me," commented one student, while another said "We had to determine our own path. It was very self-taught. That's how life will be when you get out."

Table 2: REU Student Predictions and Assessments of Learning Outcomes

	Responses
Student Predictions from First Day Specifically, what do you plan to learn or be able to do as the result of the REU program at SMU? Please complete the following sentence: "As the result of participating in REU, I will (be able to, learn, understand, etc.)……."	•be able to learn about using lots of high edge lab facilities in conducting various experiments. •be able to learn different aspects of research, i.e., how to conduct hands-on research. •be able to grasp abstract concepts, research them in a self-guided manner, and produce results that are understandable to most people. •gain exposure to engineering research. •hopefully get some useful lab experience and have fun working with technology that would be otherwise unavailable to me. •be able to figure out if I want to research when I get out of school. •learn basic mechanical research methods. •learn valuable laboratory research skills that I will be able to use either in the workplace or graduate research or potentially both.
Student Assessments from Final Day Specifically, what did you learn or are now able to do as the result of the REU program at SMU? Please complete the following sentence: "As the result of participating in REU, I (am able to, learned, understand, etc.)……."	•use more lab equipment than before. •able to do research in the field of engineering. •learned procedures to conduct experiments, method of writing reports. •that uncertainty is not the end of the world. •am able to confidently approach problems with a minimum of known facts to guide direction. •collect, analyze and present data, not knowing what to expect from the results. •I learned how challenging and time-consuming research can be. In addition, I learned that I want to

	work with people instead of spending large amounts of time in research laboratory. •confidently tackle engineering projects, design, and research, even with limited knowledge.

Participant Perceptions of Engineering Research

Student perceptions of engineering research were measured by way of scaled agree/disagree questionnaire items, open-ended questions, and focus group discussion opportunities, including a collage exercise. One major theme of their responses is that participation in an REU program changed their pre-conceived notions of what working in engineering research is really like. Table 3 includes three-word descriptions by students of "research in engineering" on their First Day and Final Day. First Day student descriptors tend to focus more on the enjoyable and rewarding aspects of engineering research, while Final Day comments are more likely to include the tedious and uncertain aspects.

Table 3: Student Descriptions of Engineering Research Before and After Participation in an REU Program

Three Words That Describe Engineering Research – First Day	Three Words That Describe Engineering Research – Final Day
•consistent, hardworking, enjoy	•exciting, progressive, evolving
•innovative, astounding, necessary	•complex, intricate, demanding
•eye-opening, valuable, interesting	•understand, experiment, apply
•time-consuming, interesting	•very, very tedious
•cutting-edge, interesting, diverse	•unknown, optimistic, meandering
•challenging, precise, rewarding	•interesting, unknown, ingenious
•abstract, unclear, optimistic	•high-tech, tedious, broad
•challenging, investigative, detailed	•challenging, detail-oriented, repetitive
•exciting, rewarding, precise	

Several directional items on First and Final Day questionnaires addressed engineering research (see Table 4). Final Day results were more positive in terms of students' belief that they were more knowledgeable about engineering research and the role of engineering research in society. Participants were also more positive in terms of their knowledge of engineering theory, making engineering measurements, and the relationship between engineering measurement and engineering design and theory. Their perceptions of their ability to work with teams and use specialized equipment for engineering projects did not appear to change significantly.

Finally, a collage exercise required students to select three or more images and words, which had been previously clipped from a variety of magazines, which they would use to represent "How I Feel about Engineering Research." Final Day collages tended to include images of uncertainty, unexpected results, and perseverance. For the collages, the students were

given the following question: "I'm going to ask you to make a very simple collage by choosing two or three or more images and words from the hundreds of cut-outs on the table to represent HOW YOU FEEL ABOUT ENGINEERING RESEARCH. In other words, what does engineering research mean to you?" Participant descriptions of their collages included:

The watch symbolizes the many measures you have to take. The camera shows that you take pictures of everything. 'Shine on' shows a glimpse of hope in a project and helps you keep going.

'Step into tomorrow' – our job is to improve stuff. Time-consuming. 'New uses' for everything. You're working toward an end, and outside your comfort zone. You don't always make sense – there are unexpected results.

'Green watch' represents flexible time – our schedules. 'Great opportunity.' More time would improve things, like the experiment. 'Creative.' What we did was very creative. Like artists, we are creative.

Picture of a measurement tool. 'Keep the faith.' Don't get frustrated even if you want to quit. 'Breaking news.' Do R&D behind something that makes it to the market.

Mine is opposite. 'Frazzled girl.' Frustrated. I felt like this some days. 'Blank picture frame.' You don't always know the end result. You feel obligated to apply engineering training to an unknown cause – it's like a divine mission.

Table 4: Student Attitudes Before and After REU Participation*

	Before # agree (9 responses)**	**After # agree (8 responses)**
I am confident that I will be able to obtain the job I want after graduating from college.	9	8
I am interested in attending graduate school in engineering.	8	5
I feel that the Engineering curriculum at my current university contains sufficient 'hands-on' experience.	6	4
I feel I am knowledgeable about engineering research.	2	7
I feel I am knowledgeable about the role of engineering research in society.	3	8
I feel I have adequate experience in working with teams on engineering projects.	4	3
I feel I have adequate experience in working with specialized engineering equipment.	2	3
I feel I have adequate knowledge of engineering theory.	2	5
I feel I have adequate experience with the proper methods of making engineering measurements	4	6
I feel I understand the relationship between engineering measurement and engineering design and theory.	2	7
I feel that as the result of the REU program, I now have considerable 'hands-on' experience in engineering.***	_ _	7

*A five-point scale from Strongly Agree (5) to Strongly Disagree (1) was used. This table reflects the number who checked a 5 or 4.

**Questionnaires for the "Before" measurement were completed on the afternoon of the First Day on campus, following an orientation session. "After" questionnaires were completed on the Final Day, after all REU activities were completed.

***Item asked on Final Day questionnaire only.

Engineering Graduate Study

Research programs that include undergraduate students, such as the REU program, are considered to be a very effective method of attracting and retaining talented students in science and engineering.[1,2] Thus questionnaire and focus group questions were used to evaluate the influence of the program on students' desire to pursue a career in research and attend graduate school. Eight of the nine participants reported on the First Day questionnaire that they were "interested in attending graduate school in engineering" (see Table 4). That number dropped to five of eight students who completed the Final Day questionnaire. Responses from the focus group discussion about whether participants' career aspirations had changed as the result of the REU program suggested that they wrestled with whether they wished to pursue additional study and/or work that was as intensely focused as their REU projects. Some of the student quotes included:

Yes, mine changed. I learned that I want something more hands-on. I want to be a bigger part of something, and not a small project with a larger goal.

Coming in, I didn't want to go to a large company, and I'm the same way now. I still want to be entrepreneurial, but now I don't want to go to grad school. It's out of the picture.

Mine changed a bit. I would like to do something smaller and entrepreneurial. Research and development, yes. But I need something more social. If I was the only one taking notes and readings in the lab, I would shoot myself. I need interaction.

Same. I'm still open to engineering. I still have a lot of possibilities, and this is one.

Same. I still want to go into the automotive industry, but I want more practical work, and not only analyzing data.

Same. I want to go into aerospace and aerodynamic work with a company like Bell Helicopter or Lockheed.

Evaluation of the REU Program

Several questionnaire items and focus group topics allowed students to predict or reflect upon aspects of their REU experience. Unanimously, students reported that their primary goal of gaining first-hand experience in a laboratory setting was achieved. "Great experience in the lab," said one student. Another said "a chance to work with intelligent and diverse people." Another commented that the experience provided "a basic foundation for my future career in mechanical engineering and the automotive industry."

When asked about the challenges of an REU program, First Day student responses reflected a perceived lack of preparedness – "My limited engineering research background," or "getting caught up with my specific discipline since I am not an upperclassman." Final Day comments often reflected the students' ability to deal with situations they did not face in their classroom studies. "Fixing unintended problems" was one student's comment, and another said "too many variables that needed monitoring/adjustment with regard to my research, and thus I made little progress."

Suggestions for improving the REU program included providing more and closer interaction with professors, ongoing discussions about potential outcomes and adaptations of project guidelines, and a more defined schedule.

Discussion

The purpose of this paper was to chronicle the preparation for and execution of an REU program in the first of a three-year cycle. The paper details how the program was publicized, how the applicant pool was analyzed, and pre- and post-program feedback from student participants.

Based on the results of the applicant and participant evaluations, several changes will be made to the REU program in 2008 and 2009. Promotional materials will include more information on housing arrangements, the number of students in the program, and faculty mentor to student ratio. Since the most effective method of promoting the program was faculty members at the applicants' institution, the PIs will make a stronger effort to contact other department chairs to help promote the REU Site to their students. More information on the REU work schedule will be provided to the participants during the orientation. One particular aspect will be a discussion of the flexibility of their schedules and expectations from their research mentors. The PIs will also develop a seminar on graduate school that will be conducted near the conclusion of the REU program. The seminar will include information on choosing a graduate school, the application process, finding a graduate advisor, seeking funding for graduate school, and the process of getting an advanced degree.

In addition to programmatic changes, evaluation methodology will also be altered to improve feedback about the program. Improved questions about how prospective participants learned of the REU program and how they reacted to promotional messages will be included. More diagnostic questions will also be asked about their plans to attend graduate school, in order to evaluate the effectiveness of the graduate school seminar. Questions about the value of the field trips will be included to determine if this impacted students' views of engineering research and their career goals.

Conclusions

A program which included undergraduate students in hands-on experimental research in the Department of Mechanical Engineering at Southern Methodist University was implemented and evaluated using surveys and focus groups. A survey of applicants indicated that family members were more influential than teachers or counselors in their decision to pursue an engineering degree. Most applicants were interested in pursuing graduate school and/or a career

in research. Many of the applicants were applying to the REU program to gain some form of hands-on experience or research experience.

Evaluation of the participants through before and after surveys and focus groups provided important information about the effectiveness of the program. As a result of the program, participants had a better understanding of engineering research and the role of engineering research in society. Students also felt they had a better understanding of the relation between engineering measurements and engineering design and theory. Student perceptions of engineering research changed significantly as a result of the program. At the beginning of the program, student descriptions of engineering research emphasized the rewarding aspects of engineering research. At the conclusion of the program the student descriptions were more likely to emphasize the unpredictable, tedious, and time-consuming nature of research.

The evaluations of applicants and participants also provided important information about the programmatic aspects of the REU program. This information will be used in the upcoming summer program to improve promotional materials, better inform students of expectations, and answer common questions about housing, dining and REU activities.

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