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Research Experiences for Undergraduate Engineering Students

Dr. Sheng-Jen "Tony" Hsieh, Texas A&M University

Sheng-Jen ("Tony") Hsieh is a professor in the Dwight Look College of Engineering at Texas A&M University. He holds a joint appointment with the Department of Engineering Technology and the Department of Mechanical Engineering. His research interests include engineering education, cognitive task analysis, automation, robotics and control, intelligent manufacturing system design, and micro/nano manufacturing. He is also the Director of the Rockwell Automation Laboratory at Texas A&M University, a state-of-the-art facility for education and research in the areas of automation, control, and automated system integration.

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Abstract

National surveys in 2011 and 2012 showed a continuous decline in the number of U.S. students who move on to attend graduate school. In addition, there is a shortage of highly educated skilled workers in the manufacturing sector. The paper will describe program activities, student research projects, outcomes, and lessons learned from a summer research program for undergraduate engineering students. Students were recruited from colleges throughout the U.S. from disciplines such as mechanical, manufacturing, electrical, and biomedical engineering and computer science. Special effort was made to recruit students who had limited opportunities to participate in research on their home campuses or belonged to groups that are traditionally underrepresented in engineering and science. Program objectives were to help participants to understand the research process, to acquire laboratory skills, and to be well-positioned for graduate school and career success. Participants spent 10 weeks working on a research project with a mentor and a graduate student. Opinion survey data suggests that students enjoyed the program and learned from the research experience. Eleven out of 16 students who have graduated are currently attending graduate school, and eight papers have been published.

Motivation

National surveys in 2011 and 2012 showed a continuous decline in the number of U.S. students who move on to attend graduate school [1]. In addition, there is a shortage of highly educated skilled workers in the manufacturing sector [2]. With increased pressure for accountability in undergraduate education from stakeholders such as parents and state legislators, higher education institutions are investigating avenues to improve the quality of education. Prior studies by Brownell and Lynn [3], Crowe and Brakke [4], Laursen [5], Lopatto[6], Taraban and Blanton [7], Russell et al [8], and Zydney et al [9] suggest that undergraduate research holds some of the answers to increasing student learning, retention, graduation rates and entrance into graduate programs. As a result, institutions across the country, as well as government agencies such as the National Institute of Standards and Technology (NIST), are providing more research experience opportunities for undergraduate students [10]. The National Science Foundation (NSF) has a program called Research Experience for Undergraduate (REU) which provides funding for universities to host a REU sites for 10 to 12 students per summer. The program also provides funding to supplement ongoing funded projects; the supplement can support one to two undergraduate students to work on research projects during the summer. Participants receive meals and lodging and a stipend (usually about $600/week).

Brownell and Swaner [3] suggest the following strategies for implementing high-impact practices such as research experiences.

- Encourage faculty to provide mentoring, rather than just program oversight, and attend to the quality of the mentoring relationship (balancing challenge with support).
- Provide opportunities for “real-life” applications, whether through publication, presentations, or project implementation.
- Offer intentionally designed curricula that enhance students’ research skills and build those skills over time, including prior to intensive undergraduate research experiences.

Overview and Objectives

This paper describes an NSF funded REU site focusing on imaging media, techniques and applications in different engineering disciplines and presents survey results and lessons learned from hosting the program for three years.

Imaging is the process of capturing a picture of an object using media such as ultrasound, infrared, near-infrared, X-rays, and magnetic fields. Imaging techniques reveal different characteristics of objects and are essential for applications and research in many industries and scientific and engineering disciplines. For example, manufacturing engineers use ultrasound imaging techniques to inspect welding joints in the oil and gas industries. Quality engineers in the electronics industry often use X-ray, infrared and/or optical imaging techniques to inspect solder joints and/or missing components on printed circuit board (PCB). Magnetic resonance imaging (MRI) is commonly used by biomedical engineers and medical professionals to examine parts of the human body. However, most undergraduates do not have opportunities to learn about imaging tools and techniques used in industry and/or research. In addition, different engineering disciplines typically focus on particular imaging techniques. For example, X-ray techniques are most likely to be covered in manufacturing engineering related courses and MRI techniques are often taught in electrical engineering.

The goals of the REU site included: (1) actively recruit students with diverse backgrounds to engage in research; (2) educate students about how research works; (3) provide a research community for students to engage in active learning about imaging media, techniques, and applications; (4) encourage students to continue on to graduate school; and (5) assess the outcomes of this experience by soliciting student inputs and monitoring their future endeavors.

Students assisted with research projects that involved designing and carrying out experiments, conducting hypothesis testing, and evaluating the experiment results. Throughout the experiments, imaging techniques were used to acquire data about objects of interest. Each participant received a stipend of $450/week for participation in the program. Other benefits include housing, meal and travel allowances; 1.0 credit hour of undergraduate course credit; and full access to university recreational facilities.

Student Recruitment and Selection

The program targeted students who 1) have limited opportunities to participate in research on their home campuses; or 2) belong to groups that are traditionally underrepresented in engineering and science, including women, underrepresented minorities, and persons with disabilities. A flyer was designed and e-mailed to department heads at approximately 100 institutions, followed by a telephone call to ensure the message had been conveyed successfully and the flyer posted appropriately. The flyer included information about program’s focus, duration, stipend, eligibility, deadline, and a link to an online application form. Campus visits were also conducted to meet with faculty and students in classes and at student professional organization meetings. Our hope was that faculty at these campuses would not only recommend students for our summer program, but also continue to advise these students on their home campuses after the program was over.

A web page was created to allow applicants to see the research projects, mentors, and activities. The application package needed to include (1) a personal information data sheet, (2) an official transcript, and (3) a recommendation letter. The personal data sheet allowed the principal investigator (PI) to group applicants based on their research interests. The PI then worked with each individual mentor to select participants.

General Program Information

As described earlier, the program's goals included: (1) educate students about how research works; (2) provide a research community for students to engage in active learning. To achieve these goals, the following activities were provided:

<u>Presentations on research methods and imaging techniques</u>

To learn about research methods, students had to opportunity to attend presentations on topics such as how to write an abstract, how to do a literature review, how to set up a working hypothesis, and how to conduct statistical testing. Students also attended presentations on imaging technologies, such as magnetic resonance imaging (MRI) and infrared imaging, and applications of imaging. The presentations were given by faculty member and/or special speakers.

<u>Individualized research experience</u>

Each participant worked on <u>a research project or area of his or her interest</u> on a team with a designated faculty mentor and Ph.D. student. This is achieved through a multiple step selection process. First, the program matched students to projects based on student interest as indicated in the application package. Second, the mentor talked to students to verify their interest and background. Third, the students were notified about their project and mentor. To ensure each student would receive sufficient attention, each mentor supervised up to two participants per summer and each student worked on a team with a mentor and graduate student. In addition, the project scope and depth were adjusted by the mentor based on student performance. Following is a sample list of research projects.

- Development of Experimental Model for Hyperemic Thermal Response Using IR Imaging
- Football Helmet Design for Impact Detection
- Surface Roughness on Bacterial Adhesion to Glass
- Comparative Analysis of Pulse and Active Thermography for Investigating Hidden Solder Joint Integrity
- 3D Tracing and Validation of Mouse Brain Vasculature
- Unraveling of the Relationship Between Modulus and Mesh Size in PEGDA and PEG star Based Hydrogels
- Processing and Characterization of $LiFePO_4$ Thin Film Cathodes for Lithium-Batteries

- Effects of Hydrogen Peroxide and Isopropyl Alcohol on the Mechanical Properties of Bovine Bone
- Classification and Localization of Retinal Image Artifacts based on Multi-Channel Histogram Analysis
- Utilizing Thermal Imaging for Investigation of Chicken Embryo Development
- Reducing Error and Power in Parallel Excitation Based on Coil

Project topic areas included material characterization, mechanical design, product defect detection, and classification of bio-images. The imaging media included optical, infrared, and MRI. The research tasks included modeling, algorithm design, conducting experiments, and statistical analysis. Also, the engineering disciplines included manufacturing, mechanical, materials, bioengineering, and electrical engineering. The REU program had a very strong inter-disciplinary flavor which allowed participants to learn from each other.

Community of active learning

Several actions were taken to facilitate the formation of a community of active learners. First, all REU students were housed in the same dormitory, including students from other REU programs. Therefore, they can interact and learn from each other; since they are most likely in different projects and from different projects. Most importantly, they all have the same goal: to learn how to do research. Second, at "brown-bag" lunch meetings, each REU student would present about their project, progress, and difficulties. Third, they were required to write a paper step-by-step throughout the summer, including the literature review, conducting the experiments, performing data analysis, and writing the conclusions. Last, they were required to (1) create a poster to summarize their work, (2) present their findings at a university-wide poster session, and (3) respond to their peers' questions about their projects. In addition to working on a research project, participants would also attend workshops and field trips related to imaging technology, science and engineering research, and planning for graduate school. Some of these activities were sponsored by Texas A&M University's Office of Undergraduate Research and involved participants from other REU and undergraduate research programs. Others provided opportunities for participants and their mentors to come together and exchange ideas and experiences and to begin to establish a research community on themes related to imaging.

Career Development

Students were introduced to research conventions and opportunities through a weekly Career Development series. The program provided lunch to encourage an informal atmosphere with plenty of student-faculty and student-student engagement. The Career Development series included a Career Day in which TAMU alumni were invited to discuss their own career evolution. Every effort was made to ensure that the speaker diversity reflected that of the REU students, so that students could envision themselves taking the speakers' paths. Further student-faculty interaction was provided through weekly faculty research seminars. Each week, one faculty member presented brief vignettes of their research interests to the group, enabling students to learn of other imaging related research beyond their own projects.

In addition to the program-related activities, students participated in several University-wide enrichment events. These activities included a weekly brown-bag seminar series on topics such as Ethics, GRE preparation, Getting into Graduate School, and Abstract Writing. Additionally, tours of campus research facilities (e.g. cyclotron, immersive visualization center) were offered. Finally, students were required to participate in the campus-wide REU poster session held during the first week in August. Students kept their posters for presentation at national or regional conferences and to display in their home departments to facilitate recruiting.

Social activities

REU students were integrated into the larger Texas A&M research community—over 200 undergraduates were involved in a dozen REU and other formal summer research programs in 2011. Students were housed with students from these other summer research programs in a modern dormitory that included a fitness center, a movie theater, and a pool. The dormitory was within easy walking distance to the College of Engineering. This housing arrangement along with membership to the University's recreation center provided opportunities for a number of social activities, including intramural softball competitions, rock wall climbing, and weekend trips.

All students also attended the campus-wide pizza party held at the conclusion of the first week to network with summer researchers from a variety of disciplines. TAMU students, who pride themselves on the Aggie tradition of hospitality, were encouraged to act as hosts for our REU students to supplement the usual social events organized at the research-group level. Table 1 provides a sample of scheduled social events, career development workshops, research seminars, and field trip activities.

Table 1. Schedule of Activities

Week 1	Welcome Pizza Party * Kick-off Meeting and Orientation * Initial meeting with faculty mentor * Work area tour * Tour of University library and seminar on using library resources * Research seminar: *Infrared imaging principles, processing, and applications (Hsieh)*
Week 2	Seminar: *Getting into Graduate School* * Field trip: M.D. Anderson Cancer Center, Houston, TX * Research seminar: *Medical imaging techniques, signal processing and applications (Ji)*
Week 3	Seminar: *Engineering Innovation Research* * Tour: Immersive Visualization Lab * Research seminar: *Instrumentation and experiment design*
Week 4	Seminar: *Funding Graduate School* * Cyclotron Institute tour * Field trip to Solectron Texas. L.P., Austin, TX *
Week 5	Seminar: *Everyday Ethics* * Tour: Offshore Technology Research Center * Mid-program assessment *
Week 6	Seminar: *GRE Prep* * Tour: Low-Speed Wind Tunnel facility * Field trip to Zyvex Corporation, Richardson, TX * Research seminar: *Synthesis and applications of novel*

	materials and atomic force microscope (Liang)
Week 7	Seminar: *Writing Abstracts* * Tour: Microscopy and Imaging Center *
Week 8	Seminar: *How to Present Your Research* * Tour: Materials & Characterization Facility *
Week 9	Work on poster and final report * Present poster at public REU poster session and reception * Research seminar: *Imaging, thin film science and technology (Wang)*
Week 10	Present report to REU cohort * End-of-program assessment

Activity Highlights

In addition to working on their research projects, participants attended research presentations, career-development workshops, and social activities with other students involved in REU and summer research programs at Texas A&M University. During the last week of the program, they presented their work at a university-wide poster session and completed papers summarizing their research. Below are photos and abstracts from the poster session. Figure 1 shows a weekly research presentation. Figure 2 shows the university-wide poster session sponsored by Texas A&M University's Office of Honors and Undergraduate Research.

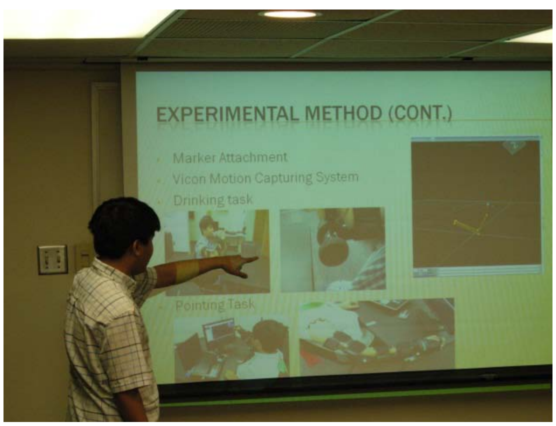


Figure 1. Presenting research to REU cohort.

Figure 2. University-wide poster session.

Figure 3 shows an example of a project abstract. A bound volume of all the REU project abstracts was provided each poster session participant. Figure 4 shows snapshots of a participant drinking from a water bottle for an REU project on imaging and analysis of human arm reaching kinematic with elbow joint constraints.

Participant: Nguyen Hoang

Mentor: Nina Robson

Title: Imaging and Analysis of Human Arm Reaching Kinematic with Elbow Joint Constraint

Abstract: The paper seeks to define some of the computational mechanisms by which the motor system finds optimal solutions, and use them to improve the flexibility of robotic systems that operate in challenging environments, such as space explorers, robots for medical assistance and prosthetic limbs. Aiming towards developing strategies designed to enhance performance following sudden arm impairment, we capture the motions of the constrained human arm and study how they solve the problem of motion planning when they lose the ability to move their elbow joint.

Results show that when the elbow is restrained, the wrist center moves on a surface, close to a sphere, with a radius equal to the distance between the shoulder and wrist and an origin located at the shoulder center of rotation. The arm is assumed to rotate around the axis of the glenohumeral joint, which acts at the center of rotation. The paper shows that the wrist trajectory follows a geodesic on the spherical workspace and compares the empirical trajectory of a restricted arm to a simulated six degree of freedom general SS open loop kinematic chain. Based on the experimental identification of the human computational solution, we propose improved recovery strategies for robotic manipulators with failed positioning actuators.

Figure 3. Sample paper abstract – 2011 participant

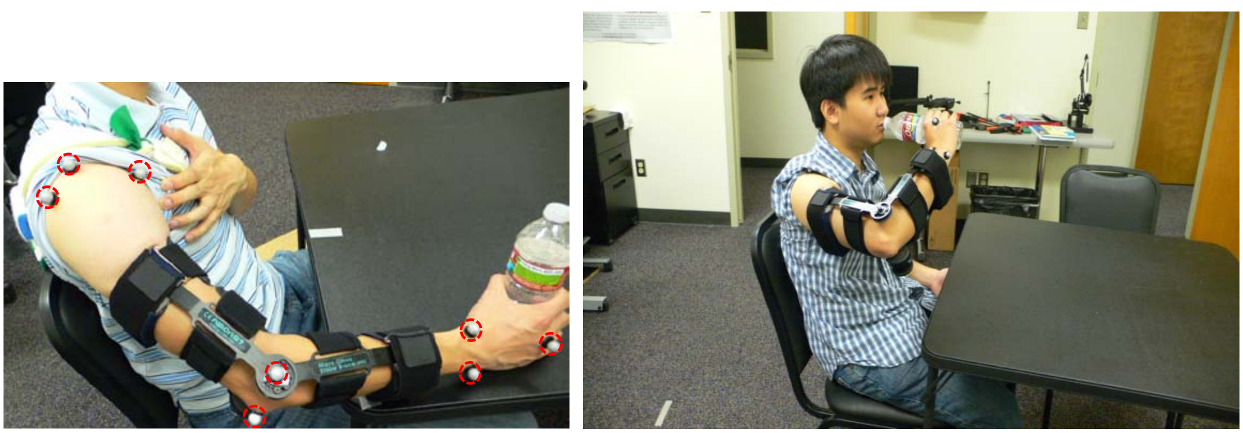
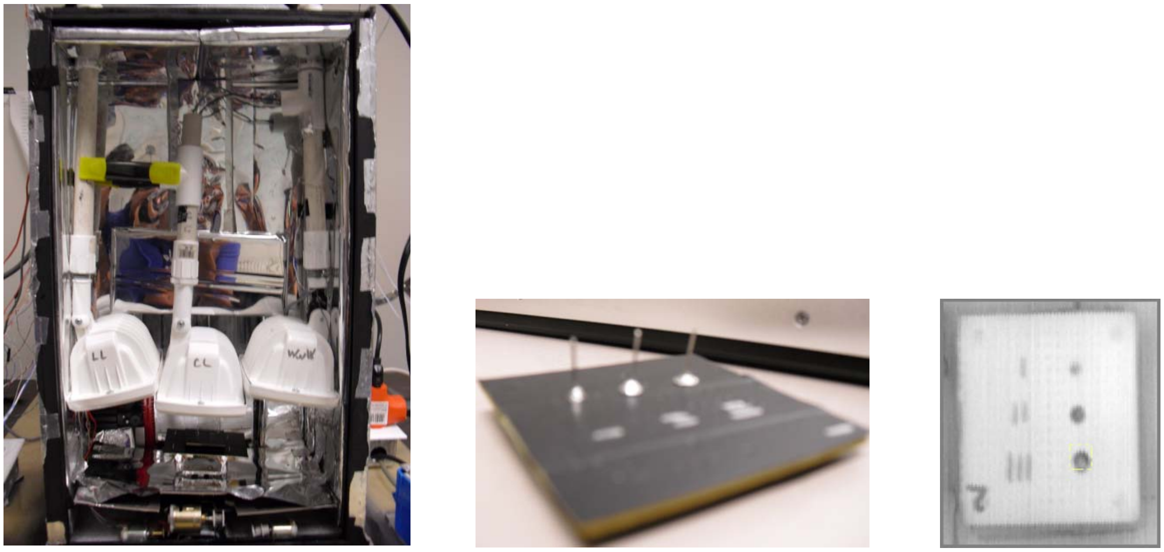


Figure 4. a) Marker attachments on the right-arm; b) experiment procedures captured by a VICON 3D motion capturing system

Figure 5 shows snapshots of an REU project titled "Comparative analysis of pulse and active thermography for investigating hidden solder joint integrity."



(a) (b) (c)

Figure 5. (a) Heating chamber; (b) printed circuit board (PCB) with solder joints with three different geometries; and (c) infrared image of PCB after heating experiment.

Dissemination and Long-term Tracking of Students

REU research results were presented at an REU poster session sponsored by the Office of Undergraduate Research at Texas A&M. In addition, some participants' work was presented at research conferences. <u>To keep track of participants after they completed REU program, we kept communications open with the students and their advisors.</u> To encourage active involvement of faculty at the students' home campuses, we specifically asked faculty to recommend students for the program, and to be involved in the selection of their student's research project. So far, the REU program has had 20 participants. The PI still maintains contact with the participants.

Results

As mentioned above, this site has hosted 20 participants, including 12 from underrepresented groups. Eight have published papers as a result of their project [11-18]. Of the 17 former participants who have graduated, nine are pursing graduate study in engineering or science; two are in medical school; and six are working in STEM fields. Of the six that are working, three are in positions that involve research.

Below are results from a survey sent to the 2011 batch of participants. The surveys were sent during March of 2012, about seven months they completed the summer program. Completion of the surveys was anonymous and voluntary, and five of the nine participants responded.

The REU program has three main objectives. The first is to help students to develop research skills (such as reviewing literature, conducting experiments,

Answer Options	Response Percent	Response Count
Not met	0.0%	0
Partly met	0.0%	0
Mostly met	20.0%	1
Completely met	80.0%	4
	answered question	5

The second objective is to help students become more informed about what a career in research involves. To what extent was this objective met for you?

Answer Options	Response Percent	Response Count
Not met	0.0%	0
Partly met	0.0%	0
Mostly met	20.0%	1
Completely met	80.0%	4
	answered question	5

The third objective is to position students for a successful transition to graduate school. To what extent was this objective met for you?

Answer Options	Response Percent	Response Count
Not met	0.0%	0
Partly met	0.0%	0
Mostly met	60.0%	3
Completely met	40.0%	2
	answered question	5

How would you describe the likelihood of your attending graduate school?

Answer Options	Response Percent	Response Count
I do not plan to attend graduate school.	0.0%	0
I am not sure if I will attend graduate school.	0.0%	0
I am likely to attend graduate school, but have no	0.0%	0
I have definite plans to attend graduate school.	100.0%	5
	answered question	5

If there was an opportunity for you to pursue research in an area of your interest, would you go for it?

Answer Options	Response Percent	Response Count
No	0.0%	0
Maybe	20.0%	1
Yes	80.0%	4
	answered question	5

Do you feel comfortable contacting your mentor for advice about research or graduate study?		
Answer Options	Response Percent	Response Count
No	0.0%	0
Maybe	0.0%	0
Yes	100.0%	5
	answered question	5

To what extent did the program meet your expectations?		
Answer Options	Response Percent	Response Count
Did not meet my expectations	0.0%	0
Partially met my expectations	0.0%	0
Mostly met my expectations	20.0%	1
Completely met my expectations	80.0%	4
	answered question	5

Would you recommend the program to another student?		
Answer Options	Response Percent	Response Count
No	0.0%	0
Maybe	0.0%	0
Yes	100.0%	5
	answered question	5

Responses to the question "What was the most memorable part of the experience?" included:

- Seeing/testing the final product of my experiments
- Exploring the campus and surrounding area with the other students in my REU program.
- I had dinner with my mentor and the graduate student whom I worked with at the end of the program.
- meeting new people
- Get excited about research.

Responses to the question "What was the most challenging part of the experience?" included:

- Long hours growing cells
- Learning how to design a research project from start to finish
- I think the most challenging fact about the experience is designing the right protocol for the experiment and perform the analysis.
- working on my own so much
- Not be able to visit home half way through the program.

Responses to the question "How can the program be improved?" included:

- More interaction with other REU programs over the summer.
- Have projects better prepared to start within the first week or two of the program?
- I think the program is perfect.
- Provide a longer length of the program.

In the "Any other comments?" section, one student wrote "I think the program should be maintained, because it really helped me becoming a better thinker and organizer of my work. In addition, I feel like I have matured in my logical thinking after spending the time in the Texas A&M University Imaging program. The experience was beyond my expectation; most importantly, it gave me the chance to explore new technology and how to apply some of it for my future research."

Conclusion and Future Directions

There is an urgent need to increase the number of successful undergraduate students in STEM fields. Studies have shown that involving undergraduate students in research-oriented activates holds some of the answers to increasing student learning, retention, graduation rates and entrance into graduate programs. What is needed are (1) continuous efforts to engage students in course research projects, senior design project and collaborative internship projects, (2) long-term tracking of student learning, research performance and ultimately professional performance and/or graduate work performance, and (3) finding methods that work by investigating the correlation between program elements and success in work or graduate study.

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Note: Asterisk (*) denotes REU participant co-author.

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