2018 ASEE ANNUAL CONFERENCE & EXPOSITION
JUNE 24–27, 2018
SALT PALACE CONVENTION CENTER
SALT LAKE CITY, UT

Paper ID #22487

A Research Experience for Undergraduates (REU) Program Coupling Energy-related Research with Training in Entrepreneurship

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ABSTRACT

This presentation will highlight the findings from the first two years of an NSF-funded research experience for undergraduate (REU) program located in the Department of Chemical Engineering at Louisiana State University (LSU). The authors noticed in recent years that many undergraduate students avoid enrolling in graduate school because they believe the only path for someone with a Ph.D. in engineering is as a faculty member. To address this limitation, the authors have developed a 10-week program that couples traditional research-related activities with training in entrepreneurship. The concept was to show students how both fundamental and applied research can lead to start-up companies, patents, and industrial partnerships. Additionally, in the part of the country where LSU is located, there are numerous small universities and colleges that do not offer research programs for undergraduates, so this REU site is a rare opportunity for these students to perform undergraduate research. The research theme for this program is energy: specifically, catalysis, energy storage, and biofuels due to the pronounced expertise in these areas at LSU. A major strength of this REU program is the partnership with the LSU Business & Technology Center which provides the REU students with training in technology transfer fundamentals and how to pitch scientific ideas to non-scientists. In addition to the entrepreneurship training, the program offers weekly seminars in ethics, effective presenting, applying to graduate school, industrial safety, and topical seminars related to three main research areas of the programs. The students were assessed individually (weekly reports), by their mentors (electronic survey three times during the 10 weeks), and by an external evaluator (portfolios). The overwhelming response from the students was positive with many learning about new opportunities for someone with a Ph.D. degree. To date, the program has been offered during the summer of 2016 and the summer of 2017 with a total of 19 students participating in the program mentored by 11 different faculty members from three different engineering departments (chemical, biological, and environmental). Of the three students that have graduated from their undergraduate institutions, two have enrolled in post-graduate training further demonstrating the effectiveness of the program.

INTRODUCTION

This unique REU site utilizes the strengths of Louisiana State University (LSU) in energy research to engage participating students in innovative projects related to biofuels, energy storage, and catalysis. Participants interact with university faculty as well as local industry and entrepreneurs. Over the course of the summer, students develop a commercialization plan for their summer research project aided by mentors from the LSU Business & Technology Center. The combination of local industry, entrepreneurship, and world-class research facilities and faculty offer the REU students an opportunity that is hard to match. In recent years the authors have discussed the unique opportunities available to those with graduate degrees with undergraduate chemical engineering students at LSU. Through these discussions a common misconception emerged: many students stated they did not want to pursue graduate degrees because they did not want “to teach”. The students believed there was no reason to pursue a Ph.D. unless one wanted to become a professor. The authors strongly believe in undergraduate research opportunities and have several undergraduates working in their labs. While these research interactions have proven valuable for both the faculty and the students, the authors felt like it would be good to expose undergraduates

with interest in research to additional mentors beyond university faculty. LSU is located in the heart of the petrochemical industry among the numerous plants and refineries located between Baton Rouge and New Orleans. The proximity to these industries enables LSU to have several rewarding research partnerships with many of the companies. In this REU program, we leverage these affiliations to allow students to interact with Ph.D.s working as entrepreneurs or as leaders in local industry. The goal is to allow the REU students to realize the tremendous opportunities available to those with graduate engineering degrees and to visualize themselves with advanced degrees pursuing their own opportunities.

This REU site is unique in many ways. The student interaction with entrepreneurs and professional Ph.D.s is only possible due to the unique location of LSU; however, this location could sometimes be a double-edged sword. While many undergraduates in our region are academically talented, the lure of high salaries from the expansive local industry pulls most of our students away from graduate school. The average starting salary for the most recent graduates with a B.S. in chemical engineering from LSU was ~$76,000 per year. We believe this is one reason less than 3% of our students enroll in graduate programs. This (low level) graduate school enrollment trend is similar for other regional institutions. In the last decade we have had only moderate success at recruiting engineering, physics, and chemistry undergraduates from these regional schools to enroll in a STEM Ph.D. program. This REU program exposes students to exciting graduate research and increases interest in career paths made possible through graduate degrees. This is a benefit to the students, industry, and graduate programs in our industry as students participating in the program have shown an affinity for attending graduate school after their experience. LSU had not had an REU program in the College of Engineering in over 20 years, but we have already seen an increase in graduate student applications from regional colleges and universities. Our graduate program has already admitted (with full financial support) three of our REU alumni for fall 2018 enrollment. These applications would not have arrived without the REU program.

PROGRAM OVERVIEW

The Research Experience for Undergraduates (REU) program at LSU was designed to excite undergraduate students about research, educate them about proper research behavior, and engage them at multiple levels in and out of the laboratory. While the program itself focused on three main topical areas of energy (biofuels, energy storage, and catalysis), the projects offered to the students were highly diverse and broadly fit into these topical areas based on the expertise of each faculty mentor. Our REU program strongly benefited from the large number of assistant professors at LSU who were eager to mentor an REU student and worked very closely with the students in the lab. Prior to the start of each summer, the authors reached out to faculty members from several departments on campus including chemical engineering, biological engineering, mechanical engineering, physics, and chemistry to elicit projects for the summer. The titles of the student projects for 2016 and 2017 are included in Table 1.

After the mentors and projects were identified, the next step was to design the 10-week program, which included many activities and workshops offered at LSU and around the state of Louisiana (Table 2). The goal of the workshops was to provide students with training in areas besides just standard research. To accomplish this, we developed seminars focused on laboratory safety, how to use the library, research ethics, effective communicating, how to apply to graduate school, how to apply for graduate fellowships, and a panel discussion led by current graduate students in the

chemical engineering department at LSU. Each of the seminars lasted ~60 minutes and was led by volunteers from departments across campus in Environmental, Health, and Safety, Library Sciences, the Communication across the Curriculum program, and others. Additionally, three faculty members from the chemical engineering department gave a seminar on each of the three focal areas of energy research (biofuels, catalysts, and energy storage).

Table 1. List of student projects for 2016 and 2017 offerings of the program.

2016	Engineering conductivity in metal oxide nanowires
	Evaluation of growing conditions of biopolymer accumulating cyanobacteria *Synechocystis PCC 6803*
	Ultrasonic pretreatment of microalgae for enhanced lipid extraction
	Development a microfluidic gradient generator to study lipid production in *Chlamydomonas reinhardtii*
	Anion exchange membranes with a fluorescent molecular probe for water sensing in alkaline fuel cells
	Chiral microstructures - Wet etching of Z-cut quartz
	Effect of NaOH on CO_2 sequestration to decrease mass release of stabilized fluorogypsum
	Sulfur-tolerant reforming catalysts for CO_2 reforming
2017	Transition Metal-doped Rare-earth Oxysulfide Catalysts for High Temperature Dry Reforming of Methane
	Ammonia-Based Flow Battery
	Investigating exposure time, freezing rate, and cell concentration parameters of cryopreservation for Nannochoropsis sp. using dimethyl sulfoxide
	Computational modeling of doped discharge products in Lithium-AIr batteries
	SUNstrips: Water Purification for Developing Countries
	The effects of fluid shear stress on cancer cell deformation and migration
	Novel Synthesis of $SrNbO_3$ for Photocatalytic Water Purification
	Photosynthetic Organisms as Micro-Bioreactors of Polyaspartic Acid
	Spray Deposition of Gold Colloids for Photodisinfection
	Magnetic Field Directed Assembly of Colloids in Drying Droplets: From Surface Patterns to Actuating Materials
	A DEM Study of Particle Clustering in a Cylindrical Vessel Undergoing Orbital Motion

To demonstrate to students that Ph.D. engineers do more than work in labs, we had a guest speaker from Honeywell talk to the students about process safety and the role of Ph.D. engineers in industry. Finally, the students participated in a series of entrepreneurship workshops given by members from the Office of Technology Transfer at LSU and the LSU Business & Technology

Center. More details on these workshops are discussed below as this was a central component of the REU program.

In addition to seminars and workshops, the REU program was designed to include social aspects so that the students could learn more about Louisiana and be given a chance to interact with students participating in other REU programs (Figure 1). The authors worked closely with directors from other REU programs to organize and plan a welcome dinner, a faculty vs. student softball game, an astronomy night, a game night, and the Summer Undergraduate Research Forum (SURF). Additionally, students from our REU program were invited to attend workshops from other programs and vice versa which allowed an even greater degree of crosstalk between programs. The authors also arranged field trips for the students to participate in including a day trip to New Orleans, a tour of the synchrotron facility on campus, and a swamp tour. The students especially enjoyed the swamp tour because it gave them first-hand exposure to the types of land that could one day be used as farms for algal biofuels. Finally, at the end of the summer all REU students participated in a poster session where they were judged by faculty members, leadership from the entrepreneurship institutes, and staff that

Table 2. List of seminars and workshops provided to the students during the 2017 offering.

Date	Seminar Topic
May 30	Patents
May 31	Safety training and proper PPE
June 1	Library resources and how to use databases
June 8	Research ethics
June 13	Entrepreneurship workshop #1
June 15	Effective communicating
June 20	One-on-one meetings with REU directors
June 22	State of Research: Biofuels
June 27	Technology transfer
June 29	State of Research: Energy storage
July 6	Applying to graduate school and graduate fellowship
July 11	Entrepreneurship workshop #1
July 13	PhDs in industry - Process safety case study
July 20	State of Research: Catalysts

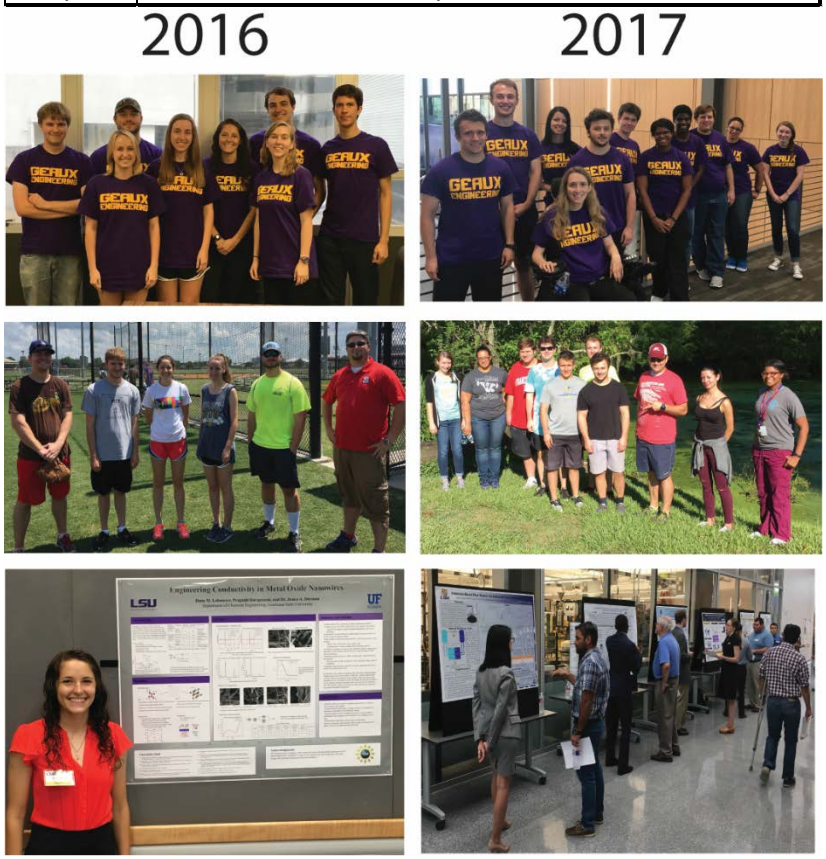


Figure 1. Images of student participants from the 2016 (left) and 2017 (right) program. (*Top*) Photos of the group from that year. (*Middle*) Students participating in the faculty/student softball game (2016) and swamp tour (2017). (*Bottom*) Students presenting their posters during the end-of-summer poster session.

participated in the weekly seminar series. Students were judged on their ability to present, the research findings, and the entrepreneurship potential of their research project. The top student(s) were awarded a travel stipend to attend the American Institute of Chemical Engineers (AIChE) Annual Student Meeting to present their work. The two winners from the 2017 offering both won awards at this meeting with one taking first place in the Food, Pharmaceutical, and Biotechnology poster session and the other taking second place in the Environmental poster session.

DESIGN OF ENTREPRENUERSHIP COMPONENT

In addition to the seminars and workshops described above, the students had multiple experiences designed to challenge them to consider how their campus research could impact society and what scientific breakthroughs or research investments are needed to make such a transformation (Table 3). The LSU Innovation and Technology Office (ITO) sent two representatives to speak with our students. ITO director and LSU Vice-President for Research, Andrew Maas (also an attorney) spoke with students about how intellectual property rights work especially with respect to collaborations between LSU and its industrial partners. Mr. Maas also provided a basic introduction to patent law and how to tell if an idea is patentable. The assistant director of ITO, Brian Shedd, discussed patents and trademarks with the cohort and provided an overview of the NSF I-Corp program. Additionally, John Flake, a professor at LSU, spoke with students for one hour about his successful start-up company, a spin-off from his university work. To date Dr. Flake has received two phases of NSF SBIR grants and was able to share some of his successes and failures with the students.

Table 3. List of entrepreneurship workshops provided to the students during the 2017 offering

Date	Topic
5/30	Intellectual Property and Patent Law Introduction
6/13	Overview of the LBTC/Student Success Stories
6/20	An entrepreneur's success story
6/27	Patents and NSF I-Corps
7/11	Feedback on Student Commercialization Ideas

The LSU Business & Technology Center (LBTC) houses a small business incubator and has a branch specifically for student-run companies. Since its inception in 2010, the student incubator has helped 29 student companies (employing over 100 people) generate over $5,000,000 in capital. The LBTC is very unique and an essential part of our students' REU experience. The executive director of the LBTC, Charles D'Agostino, is a huge supporter of the REU program and helped train the students in effective entrepreneurship. On the students' first trip to the LBTC, Mr. D'Agostino gave an overview of the facilities and shared some student business success stories. The excitement in the room was palpable as Mr. D'Agostino helped the students plan the potential commercialization of their own research. In a second visit to the LBTC, Mr. D'Agostino and his staff worked with REU students one-on-one. Students pitched their ideas to Mr. D'Agostino's team. Discussions with the team helped flesh out ideas and laid the groundwork for the end of summer student projects. The entrepreneurial training was something most of the REU participants would never have received if not for their summer experience at LSU. The interactions with real-life entrepreneurs and attorneys showed students a whole new career path for Ph.D. researchers outside of just "teaching".

RECRUITING EFFORTS

An objective of this REU site, which is like other sites across the country, was to specifically engage students from groups traditionally underrepresented in engineering (e.g., female, African American, and Hispanic students, and students with disabilities) and students from smaller institutions that do not have graduate programs and are not research intensive. The state of Louisiana and the Southeast region of the US have a substantial number of colleges and universities with large populations of traditionally underrepresented minorities. The authors directly reached out to contacts at these schools to encourage rising junior and senior students to apply to the REU program. Additionally, the authors reached out to colleagues at colleges and universities across the country to encourage students to apply to the program. The authors also presented a recruiting booth at the AIChE Annual Meeting in 2015, 2016, and 2017 to advertise the program. For the 2016 offering, 42 students applied from 27 different institutions with 45% of the applicants coming from underrepresented populations in engineering. For the 2017 offering, 41 students applied from 25 different institutions with 30% of the applicants coming from underrepresented minorities. The 2016 class consisted of 8 students with 5 students coming from underrepresented groups and 3 students hailing from non-research-intensive institutions. The 2017 class consisted of 11 students with 6 students coming from underrepresented groups and 5 students hailing from non-research-intensive institutions. The result of the recruiting efforts has been a highly diverse group of students each year which has been a major strength of the program. The placement of the students after graduation will be discussed in the next section.

RESULTS

Students were assessed by several different metrics throughout the summer. Assessment took the form of informal evaluations by the mentors and one-on-one meetings with the authors. Students were also required to submitted weekly reports detailing (i) the overall goal of the project, (ii) experiments performed in the lab, (iii) techniques learned, (iv) key findings and observations, (v) professional development activities, and (vi) goals and objectives for the following week. An example of a weekly report from one student from the 2017 program is included in Figure 2. An external evaluator performed more formal assessments twice during the summer: once during week 5 and once during week 10.

Some highlights from the end of session external evaluation for the 2017 cohort (n=11 students).

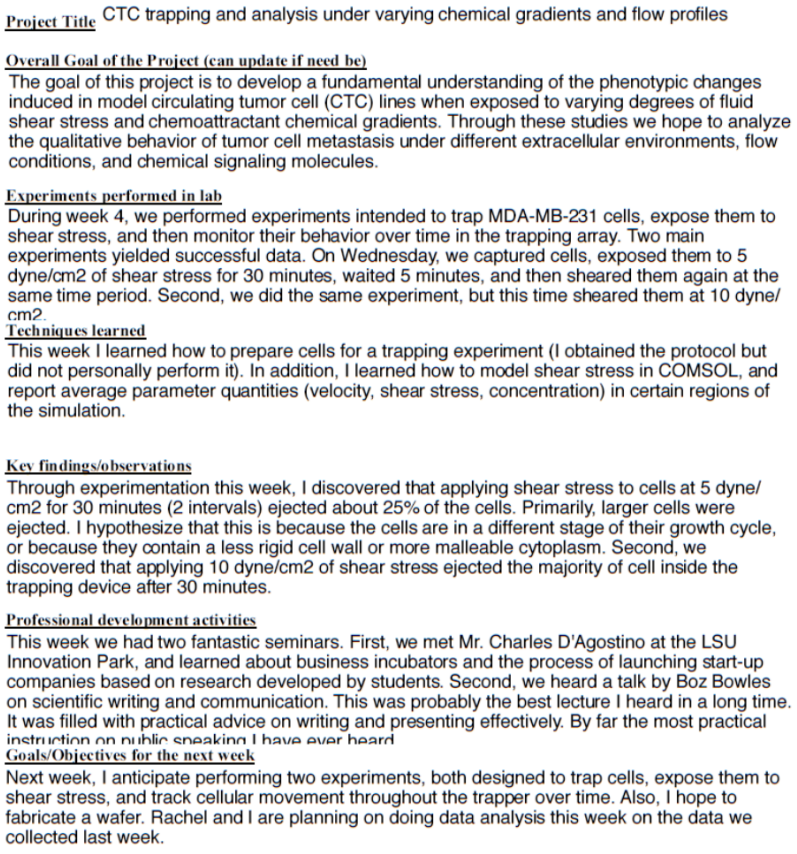
- When asked if they were satisfied with the overall REU experience, 6 students strongly agreed and 5 agreed.
- When asked if they planned on continuing undergraduate research, 9 students strongly agreed and 2 agreed.
- When asked if the REU impacted their future career plans, 9 students strongly agreed and 2 agreed.

Student responses on how the REU impacted their career plans are shown below:

- I’m very intent on going to grad school, whereas before it was a thought every once in a while.
- Making me more heavily consider grad school as a post-undergrad path
- Opened my eyes to more materials science research
- I am thinking about grad school and changing my interests.
- I am now considering graduate school.

- Made my decision on going to graduate school easier
- I was thinking of attending a graduate program other than Chemical Engineering. This has changed since I got this experience.
- It got me more interested in grad school, though maybe not in the area I researched while here.
- It made it more clear in what area of research I want to work in.

In addition to assessment during the program, the authors have tracked student decisions in years after the program. This was accomplished by a survey given to the students during the spring semester in the year following the program. The goal of the survey was to determine how effective the REU program was in influencing the students' decision to enroll in graduate school. The last survey given was in April 2017 and only included the 2016 cohort. Seven of the eight students from the 2016 group replied to the survey. Two of the three students that graduated from their undergraduate intuitions in May of 2017 had already been accepted into graduate school (Rice and the University of Texas at Austin).



Project Title CTC trapping and analysis under varying chemical gradients and flow profiles

Overall Goal of the Project (can update if need be)
The goal of this project is to develop a fundamental understanding of the phenotypic changes induced in model circulating tumor cell (CTC) lines when exposed to varying degrees of fluid shear stress and chemoattractant chemical gradients. Through these studies we hope to analyze the qualitative behavior of tumor cell metastasis under different extracellular environments, flow conditions, and chemical signaling molecules.

Experiments performed in lab
During week 4, we performed experiments intended to trap MDA-MB-231 cells, expose them to shear stress, and then monitor their behavior over time in the trapping array. Two main experiments yielded successful data. On Wednesday, we captured cells, exposed them to 5 dyne/cm2 of shear stress for 30 minutes, waited 5 minutes, and then sheared them again at the same time period. Second, we did the same experiment, but this time sheared them at 10 dyne/ cm2.

Techniques learned
This week I learned how to prepare cells for a trapping experiment (I obtained the protocol but did not personally perform it). In addition, I learned how to model shear stress in COMSOL, and report average parameter quantities (velocity, shear stress, concentration) in certain regions of the simulation.

Key findings/observations
Through experimentation this week, I discovered that applying shear stress to cells at 5 dyne/ cm2 for 30 minutes (2 intervals) ejected about 25% of the cells. Primarily, larger cells were ejected. I hypothesize that this is because the cells are in a different stage of their growth cycle, or because they contain a less rigid cell wall or more malleable cytoplasm. Second, we discovered that applying 10 dyne/cm2 of shear stress ejected the majority of cell inside the trapping device after 30 minutes.

Professional development activities
This week we had two fantastic seminars. First, we met Mr. Charles D'Agostino at the LSU Innovation Park, and learned about business incubators and the process of launching start-up companies based on research developed by students. Second, we heard a talk by Boz Bowles on scientific writing and communication. This was probably the best lecture I heard in a long time. It was filled with practical advice on writing and presenting effectively. By far the most practical instruction on public speaking I have ever heard.

Goals/Objectives for the next week
Next week, I anticipate performing two experiments, both designed to trap cells, expose them to shear stress, and track cellular movement throughout the trapper over time. Also, I hope to fabricate a wafer. Rachel and I are planning on doing data analysis this week on the data we collected last week.

Figure 2. Example of weekly student report.

The third student was still waiting on responses as of April 2016. The authors will give this survey again in April of 2018 to track the results from the 2016 and 2017 cohorts. From information discussions with the students, the authors have discovered that three students from the 2016 program and two students from the 2017 program intend to enroll in graduate school. More detailed information will be provided during the presentation after the survey results have been collected.

CONCLUSIONS

The REU program at LSU has been a success to date for all involved. The mentors have had the opportunity to work with bright students from a variety of backgrounds. This will ultimately lead to publications in scientific journals, new proposals, and opportunities for more students in the future. The chemical engineering department at LSU has benefited from increased exposure as evidenced by the increase in graduate school applications including three REU alums being offered admission for the fall 2018 class. Hopefully the students have benefited the most. They have learned that a Ph.D. is not a one-way ticket to a professorship. Although many find that to be a

rewarding career path, the opportunity for lucrative positions in industry or entrepreneurship are available. The students involved to date have had their research curiosity piqued and are more intent on pursuing graduate degrees after their participation. This is a plus for the US and the major reason funding REU programs is so important.