An NSF REU Site with Integrated Academia-Industry Research Experience – Development, Implementation and Lesson-learned

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Introduction

Smart Structures Technologies (SST) is receiving considerable attention as the demands for high performance in structural systems is increasing in recent years. Although both the academic and industrial worlds are seeking ways to utilize SST [1-9], there is a significant gap between engineering science in academia and engineering practice in the industry. To bridge the gap and facilitate the research infusion, San Francisco State University (SFSU) and the University of South Carolina (UofSC) collaborate with industrial partners to establish a Research Experiences for Undergraduates (REU) Site program, which provides undergraduate students a unique opportunity to experience research in both academic and industrial settings through cooperative research projects. Industrial companies, including Arup Group Limited (Arup), ASSET Intelligent Infrastructure (ASSET), Exponent Inc., FTF Engineering Inc, Geosyntec Consultants (Geosyntec), Kimley-Horn and Associates, Inc. (Kimley-Horn), Rutherford + Chekene, Skidmore, Owings & Merrill LLP (SOM), STV Group, Inc., and Tora consulting LLC (Tora consulting), have agreed to participate in the program. Through this unique and exciting summer research experience in both academic and industrial environments, the program intends to prepare students to become the catalysts to help close the gap between academia and industry, and motivate the participants, especially those from underrepresented groups, not only to complete their undergraduate degrees, but also to pursue advanced degrees and/or careers in engineering. The detailed program objectives and expected outcomes can be found in [10].

Participants spend a total of 10 weeks in the program. In the first two weeks, the students are hosted at the academic institutions, SFSU or UofSC, receiving training for the upcoming research activities. During this two weeks, workshops, including professional development workshops such as Applying for Graduate School, Communication and Writing Skills, The Elevator Pitch, and Entrepreneurship, as well as subject related preparation workshops such as Data Acquisition, Dynamics, Introduction to Programming, Introduction to Lab Notebook, Probability, and Project Specific Software, are offered by one of the participating academic institutions. Students not at that institution will virtually attend these through videoconferencing. During weeks 3-9, the students spend part of their time at the academic institution and the rest in industry partners working on the research projects that are predefined by academic advisors together with industrial mentors. The participants are back at the academic institution in week 10 to wrap up the program. Supplemental activities, including student formal presentations, roundtable discussion, technical tour and cultural activities, are held throughout the program.

The primary objective of these first two weeks of the program is to prepare students to acquire necessary knowledge for the upcoming research activities. Through the unique research experience (weeks 3-9), the students are given opportunities to experience research in both academia and industry, to distinguish between engineering science and engineering practice, and to bridge the gap between the research in academia and industry. This program aims to train undergraduate students to serve as the catalysts between engineering science with fundamental research and engineering practice with potential implementation. Experiencing research in both worlds – the academic world where they experience the value of guided and mentored research and the industrial world that is fast-paced and requires researchers to act independently and professionally – help students transition from a relatively dependent status to an independent a status as their competence level increases. The days the REU participants in the industrial companies increase with the program progresses to allow for transition. Supplemental activities are designed to ensure that students are on the right track and better prepare them for the next steps in their career (e.g., practice professional presentation skills; establish professional networks through student-student and student-mentor interactions).

Program promotion and student recruitment

The program recruits 8 students each year (4 at each institution). The REU program initiates the collaboration from junior and senior students, the future change makers, at their most curious stages in their academic careers. The underrepresented minority (UPM) students are the main targets of this REU program. The program is broadly advertised through the following mechanisms:

1. The identified 20 collaborating minority and primarily undergraduate institutions with limited science, technology, engineering, and mathematics (STEM) research capabilities (15 of them are HSI).
2. Public advertising at websites such as those at the host institutions and Pathways to Science [11], which places particular emphasis on connecting underrepresented groups with STEM programs, funding, mentoring and resources.
3. A public website specially created for the REU program.
4. Flyers with relevant information sent to engineering departments across the country.

A study was carried out to identified what strategies are useful. In this study, Google Analytics was adopted to quantitatively evaluate how different activities (e.g., e-mailing colleagues) affect website usage and video viewers. The results confirmed the findings from first year [12] that personalized emails to colleagues appears to be an effective way to attract potential participants. A total of 81 applicants (more than 40% were female, and more than 60% were students of color) for the first year and 105 applicants (with similar characteristics as first year) for the second year were received. The 30% increase in the applicant pool in the second year provides confidence on the effectiveness of the recruitment strategies.

Partnership with Industry

This program is built upon the long-term collaboration relationship between the PIs and the industrial partners. In the first-year implementation, SFSU was working with ARUP and SOM, while UofSC was collaborating with ASSET and Geosyntec to provide students unique research experience in both academic and industrial settings [12]. For the second-year implementation, SFSU continued partnering with ARUP and SOM while UofSC worked with two new companies, Tora consulting and Kimley Horn, to test out the benefits and limitations of working with the same companies and different ones. The research topics are collaboratively determined by the academic mentors and industrial mentors that have mutual interests to both parties. At minimum, each student was guided by two mentors, one from academia and one from industry, during this period. At one of the projects (ARUP's project), a graduate student was also placed in the team to evaluate the benefits of having a layer between the industrial mentors and the REU participants. Below are the four projects in the second-year implementation as an example:

SOM Project: Greenhouse gases trap heat within our atmosphere, leading to an unnatural increase in temperature. CO2 and its equivalent emissions have been a large focus when considering sustainability in the civil engineering field, with a reduction of global warming potential being a top priority. According to a 2017 report by the World Green Building Council, the construction and usage of buildings account for 39 percent of human carbon emissions in the United States, almost half of which are from the extraction, manufacturing, and transportation of materials. Substituting wood for high emission materials could greatly reduce carbon if harvested and disposed of in a controlled way. The goal of this project is to investigate and quantify the embodied carbons of various slab system designs through a high-rise residential complex in San Francisco as a case study. The REU participants worked directly with two industry mentors, one Associate Director and an Associate, to look into three concept designs: a concrete building with and without cementitious replacement, and a concrete building with cementitious replacement and nail-laminated timber wood inlays inserted into various areas of the superstructure slabs. The study results showed that wood substitution could decrease overall emissions and reduce the environmental footprint of the construction industry.

Arup Project: Topology optimization has the potential to reduce the carbon footprint by minimizing material usage within the design space based on given loading conditions. While being a useful tool in the design phase of the engineering process, its complexity has hindered its progression and integration in actual design. As a result, the advantages of topology optimization have yet to be implemented into common engineering practice. A prototype user-friendly Automated Topology Optimization Platform (ATOP) that streamlines various software packages in different stages of the design process, from modeling (Rhino) to finite element analysis and topology optimization (Altair HyperMesh/Optistruct), was developed through last year's REU program. This year's program builds upon the outcomes from last year and extend the capacity of the platform. ATOP allows for leading industry professionals to form a conceptual understanding of a structure's ideal shape and design in terms of material placement and various material parameters such as mesh size, volume fraction, and minimum and maximum member size at the start of a project. After getting familiar with the ATOP platform, a systematic validation on the platform was first carried out by the REU participants. Three industrial mentors from ARUP, one Senior Engineer two Engineers, were working closely with the REU participants. In addition to bug fixing, new functionality such as handling of design space and non-design space, option for convergence criteria, intelligent self-exploration, were added to the platform. Through this experience, students were able to develop a good understand of topology optimization. The results showed that ATOP v2.0 is capable to provide opportunity to fully explore the functionality and versatility of the topology optimization.

Tora consulting: Tora consulting inspects industrial facilities to determine leaks of gasses into the atmosphere. The industrial facilities targeted by this company are often large with many components that need to be tagged. Damage or leaks in components need to be specifically documented. Component in large facilities are difficult to tag because of the number of components. In addition, depending on the type of material used, tags can break over time. The company was interested in evaluating the use of augmented reality to tag components. The same technology can be used by reconnaissance teams to digitally tag structural components after a disaster.

Kimley-Horn: This project raises from the need to estimate the strength of structural elements. Kimley-Horn designs and retrofit vertical structures such as parking buildings. In some occasions the company needs to estimate the strain in some of the structural components. Structural components in parking buildings are often prestressed concrete elements. Digital image correlation (DIC) techniques have been used in other fields to estimate the strain distribution in materials. DIC uses a random pattern of dots painted in the structure. The goal of this project is to determine if other patterns could improve the accuracy of DIC methods in prestressed concrete.

One question that is very interesting to the leadership team is if exposing the undergraduate students to industrial environment would affect their decision on the future career plan and enter professional practice other than graduate school. The results are surprisingly promising. All the past REU participants in the two years' program implementation indicated the intention to go to graduate school. As confirmed by the external evaluator, this experience indeed helped to retain students and encouraged them to pursue more advanced degree. As in the evaluator's report on the second-year implementation: "All of the students had some aspirations to enter graduate study after completing their undergraduate degrees", "at the beginning of the experience, several indicated they intended to get some work experience before going on to graduate programs. When we revisited this question at the end of the REU, one of the students indicated the intention to work for some time before returning to graduate study. The others said they wanted to start graduate studies immediately after finishing their bachelor's degrees. The participants said that the REU experience had reinforced the importance of graduate study". One of the reasons behind this is that all of the industrial mentors in the companies working with the program have an advanced degree (at least a MS). Exposing students to role models with higher levels of education offers them practical insights into the benefits of pursuing not only their undergraduate degrees but also continuing their educational journey. This experience indeed provides the participants a better understanding of their career path. As in the evaluator's report: "The participants indicated that their participation in the summer REUs had provided valuable opportunities to learn about and experience research, experience real-world work environments, and to develop both hard and soft professional skills. In several cases, they had become clearer about their educational and professional trajectories". The program also provides the participants a better understanding of the difference in terms of research in academia and industry. The evidence indicates that the REU helped the students to deepen their understanding of research, and to differentiate research in academic and industrial contexts, although their understanding tended toward concrete, rather than abstract, distinctions. According to one of the finds from the external evaluator: "One aspect of the participants' perceptions of research that appeared to change from before to after their experience was an initial focus on confirming or refining ideas. By the end of the experience, the students were more likely to talk about generating new knowledge".

Through this REU program, reinforcement of relationship and establishment of new relationship are observed between the faculty mentors and industry partners. Both faculty mentors and industry partners expressed high levels of satisfaction with the REU, and interest in continuing to collaborate, both through the REU project, and in other possible projects, such as joint research, internships, and the like.

As mentioned before, a graduate student was included in one of the projects as an experiment to see if adding an additional layer between the industrial mentors and the REU participants would be beneficial to the project. Based on the feedback from the industrial partners and the academic mentor of the project, the graduate student plays a key role to the success of the projects as the graduate student supporting the project was very accessible and was able to provide the right amount of assistance to the REU participants.

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