Board 74: Development and Implementation of an NSF REU Site with Integrated Academia-Industry Research Experience for Undergraduates

Dr. Zhaoshuo Jiang P.E., San Francisco State University

Zhaoshuo Jiang graduated from the University of Connecticut with a Ph.D. degree in Civil Engineering. Before joining San Francisco State University as an assistant professor, he worked as a structural engineering professional at Skidmore, Owings & Merrill (SOM) LLP. As a licensed professional engineer in the states of Connecticut and California, Dr. Jiang has been involved in the design of a variety of low-rise and high-rise projects. His current research interests mainly focus on Smart Structures Technology, Structural Control and Health Monitoring and Innovative Engineering Education.

Dr. Juan M Caicedo, University of South Carolina

Dr. Caicedo is an associate professor at the Department of Civil and Environmental Engineering at the University of South Carolina. His research interests are in structural dynamics, model updating and engineering education. He received his B.S. in Civil Engineering from the Universidad del Valle in Colombia, South America, and his M.Sc. and D.Sc. from Washington University in St. Louis. Dr. Caicedo's teaching interests include the development of critical thinking in undergraduate and graduate education. More information about Dr. Caicedo's research can be found online at http://sdii.ce.sc.edu

Dr. Robert Petrulis, EPRE Consulting LLC

Dr. Petrulis is an independent consultant specializing in education-related project evaluation and research. He is based in Columbia, South Carolina.

Development and Implementation of an NSF REU Site with Integrated Academia-Industry Research Experience

Zhaoshuo Jiang[1*], Juan Caicedo[2], Robert Petrulis[3]

[1]San Francisco State University, San Francisco, CA 94132
[2]University of South Carolina, Columbia, SC 29208
[3]EPRE Consulting LLC, Columbia, SC 29208
*Corresponding Author: zsjiang@sfsu.edu

Abstract

With increasing demands for high performance in structural systems, Smart Structures Technologies (SST) is receiving considerable attention as it has the potential to transform many fields in engineering, including civil, mechanical, aerospace, and geotechnical engineering. Both the academic and industrial worlds are seeking ways to utilize SST, however, there is a significant gap between the engineering science in academia and engineering practice in the industry.

To respond to this challenge, San Francisco State University and the University of South Carolina collaborated with industrial partners to establish a Research Experiences for Undergraduates (REU) Site program, focusing on academia-industry collaborations in SST. This REU program intends to train undergraduate students to serve as the catalysts to facilitate the research infusion between academic and industrial partners. This student-driven joint venture between academia and industry is expected to establish a virtuous circle for knowledge exchange and contribute to advancing fundamental research and implementation of SST. The program features: formal training, workshops, and supplemental activities in the conduct of research in academia and industry; innovative research experience through engagement in projects with scientific and practical merits in both academic and industrial environments; experience in conducting laboratory experiments; and opportunities to present the research outcomes to the broader community at professional settings. This REU program provides engineering undergraduate students with unique research experience in both academic and industrial settings through cooperative research projects. Experiencing research in both worlds is expected to help students transition from a relatively dependent status to an independent status as their competence level increases.

The joint efforts among two institutions and industry partners provide the project team with extensive access to valuable resources, such as expertise to offer a wider-range of informative training workshops, advanced equipment, valuable data sets, experienced undergraduate mentors, and professional connections, that would facilitate a meaningful REU experience. Recruitment of participants targeted 20 collaborating minority and primarily undergraduate institutions (15 of them are Hispanic-Serving Institutions, HSI) with limited science, technology, engineering, and mathematics (STEM) research capabilities. The model developed through this program may help to exemplify the establishment of a sustainable collaboration model between academia and industry that helps address the nation's need for mature, independent, informed, and globally competitive STEM professionals and could be adapted to other disciplines.

In this paper, the details of the first-year program will be described. The challenges and lesson-learned on the collaboration between the two participating universities, communications with industrial partners, recruitment of the students, set up of the evaluation plans, and development and implementation of the program will be discussed. The preliminary evaluation results and recommendations will also be shared.

Introduction

With increasing demands for high performance in structural systems, Smart Structure Technologies (SST) is receiving considerable attention as it has the potential to transform many fields in engineering, including civil, mechanical, aerospace, and geotechnical engineering. Within the area of civil engineering, in particular, extreme events such as earthquakes, hurricanes, and tsunamis can have fatal effects on structures, and, as consequence, have devastating influences on occupants, society, and the economy as a whole. A smart structure is a structure that is capable of sensing, control and actuation. These systems are able to withstand these hazards by reacting to the environment, just like a biological body. National efforts are underway to develop and build the next generation of smart structures. In the academic world, researchers are developing, for example, new sensing schemes (structural health monitoring) [1-2], smart dampers and corresponding controllers (structural control) [3-4], and evaluating innovative experimental testing methods (real-time hybrid testing) [5-6]. In the industrial world, investigators emphasize on the practical applications and conduct SST research on, for example, adopting unmanned aerial systems (UAS) for non-contact vision-based health monitoring [7], applying ideas learned from nature to build more resilient structures [8], and utilizing modern computer power and topology optimization techniques to design more efficient structures [9].

However, there is a significant gap between engineering science in academia and engineering practice in industry which has previously limited the research outcomes on each side to be leveraged. To address this important issue, San Francisco State University (SFSU) and the University of South Carolina (UofSC) collaborated with industrial partners to establish a Research Experience for Undergraduates (REU) Site program, focusing on academia-industry collaborations in Smart Structure Technology (SST).

The program features: formal training, workshops, and supplemental activities in the conduct of research in academia and industry; innovative research experience through engagement in projects with scientific and practical merits in both academic and industrial environments; experience in conducting laboratory experiments; and opportunities to present the research outcomes to the broader community at professional settings. This REU program intends to (i) increase the diversity of professionals in the engineering field by recruiting a highly diverse student population, including underrepresented students, and encouraging them to pursue graduate-level training and careers in science and engineering; (ii) train students in both engineering science and engineering practice thereby producing mature, independent, informed, and globally competitive engineering graduates to meet the demand for skilled STEM professionals; (iii) establish a sustainable collaboration model between academia and industry that is designed for adoption/adaption throughout the various engineering disciplines. A more detailed description of the program including its objectives and expected outcomes can be found in [10].

In this paper, the first year's implementation of the program will be used as an example to discuss the challenges and lesson-learned on the collaboration between the two participating universities, communications with industrial partners, recruitment of the students, set up of the evaluation plans, and development and implementation of the program. The preliminary evaluation results and recommendations will also be shared.

First Year Implementation

In the first-year implementation, SFSU and the UofSC were working with Arup Group Limited (Arup), Skidmore, Owings & Merrill LLP (SOM), ASSET Intelligent Infrastructure (ASSET), and Geosyntec Consultants (Geosyntec) to provide students unique research experience in both academic and industrial environments.

Being able to attract qualified participants is a critical factor to the success of the program. Several strategies were used to promote the program. A promotion flyer was developed and sent through emails to the identified 20 collaborating minority and primarily undergraduate institutions with limited STEM research capabilities, and colleagues of the PIs. These connections were carefully selected to cover universities with different geographical distribution as well as student bodies. Figures 1 and 2 show the locations where the emails were sent to colleagues and where the applicants were located, respectively. As can be observed, they are consistent, which indicates that inviting participants through promotion emails to colleagues is a particularly effective way of promoting the program.

Figure 1. Email Distribution to Colleagues

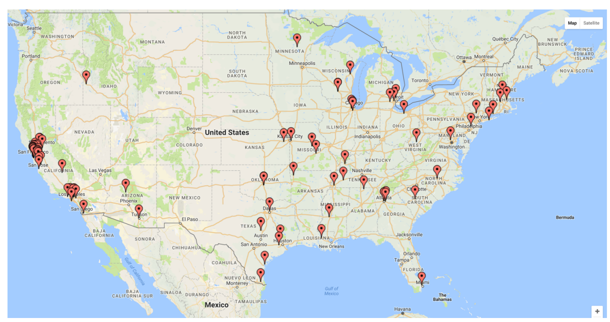

Figure 2. Applicant Distribution

Additionally, a dedicated public website [11] was created to introduce the REU program and facilitate the application process. The application deadline for the 2018 summer program was Feb. 16, 2018. There were 82 applications in total. To provide more insights on how to better attract and retain potential applicants (e.g., website reviewers), Google Analytics was adopted to quantitatively evaluate how different activities (e.g., e-mailing colleagues) affect website usage and video viewers. Figure3 shows the website traffic between Jan. 13 to Feb 18, 2018. The traffic started to increase after the emails were sent to colleagues on Jan. 13. It took 4 days to reach the peak on Jan. 18 and remained consistent till the application deadline. This further illustrates the effect of the emails to colleagues. Figure 4 shows the geographical distribution of the website users in the U.S. The data show that the website had most users from San Francisco, CA and Ashburn, VA (86 and 53, respectively).

Public advertising was also done at Pathways to Science [12], which places particular emphasis on connecting underrepresented groups with STEM programs, funding, mentoring and resources.

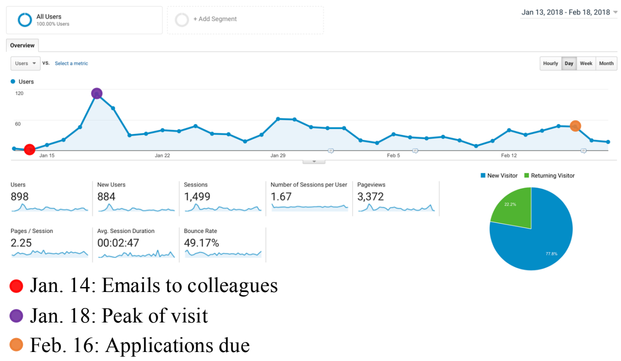

Figure 3. Website Usage Statistics

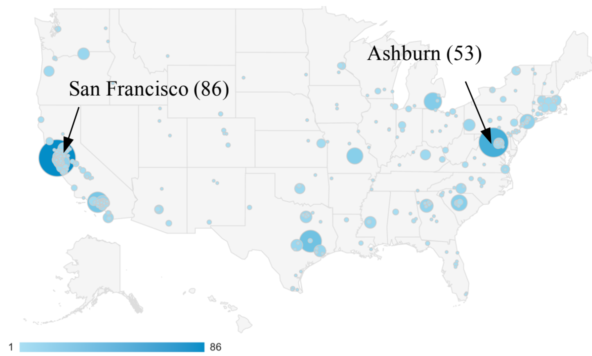

Figure 4. Website User Distributions

The REU participants spent a total of 10 weeks in the program. In the first two weeks, the students were at the academic institution receiving training (e.g., workshops and seminars) for the upcoming research activities. During weeks 3-9, the students spent part of their time at the academic institution and the rest with industry partners working on the research projects. On Friday, they typically came back to academic institutions for progress reports and extracurricular activities. The participants were 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 were arranged in the program. Figs 5 – 9 showcase various activities, including research in academic and industrial environments, in the 2018 summer program.

Figure 5. Research in Academic Environment
SFSU Participants

Figure 6. Research in Industrial Environment
SOM's Office

Figure 7. Student Formal Presentation in Industry Partner's Office - Arup


Figure 8. Cultural Activity
Academy of Science - SFSU Participants


Figure 9. Industrial Partner Leading Field Site Visit
Moscone Center - SOM

Evaluation and Results

To evaluate the project the following 8 types of data were collected to answer four evaluation questions with sub-questions for each. Finding summary is provided for each question.

1. Participation data
2. Pre- and post-tests of students' knowledge of SST and understanding of research
3. Industry partners' assessments of participating students and the collaboration
4. Students' weekly and final reports, including reflective writing assignments
5. Students' research presentations
6. Group interviews with participating faculty
7. interviews with participating undergraduate students,
8. Formal project implementation review

Evaluation question 1: What were the effects of the summer research experiences on the participating undergraduate students?
A. How successful was the project in recruiting and supporting students from underrepresented groups?

B. How do the participants understand research in the context of engineering, and any similarities or differences between academic and industrial research?

C. How do the participants describe their future roles as they become professional engineers, and how do they perceive opportunities for collaboration between academic and industrial engineering?

D. What changes in professional plans and aspirations take place among participants over the course of their summer research experiences?

E. What were the effects of participation on the students' professionalism and autonomy?

F. What were the effects of participation on the students' core knowledge in SST-related areas?

Finding Summary: Of the 81 individuals who applied for this program, 36 (44%) were female. Six women (75% of the 8 participants) accepted invitations to take part. 46 of the 76 applicants who disclosed their ethnic backgrounds (61%) were non-Caucasian, compared to four participants (50%). The students who were selected to participate roughly mirrored the ethnic makeup of the applicant pool. Of the participants, one (13%) was a white male. Through the applicant evaluation process, interviews were performed with 16 finalists to select the eight participants. This was deemed as an effective final part of the process that had allowed the program administrators to make what turned out to be high-quality decisions about participant selection. The eight participants were divided into four teams with two per team to work with four industry partners. Each academic institution (i.e., SFSU and UofSC) hosted two teams.

From the participants, the main difference between academic and industry-based research was thought to be the latter's focus on profitability, which meant providing innovative solutions to the immediate problems faced by employers or clients, or tweaking or optimizing existing processes. While industry-based research was perceived to focus on problems affecting business competitiveness, academic researchers were believed to be freer to follow their personal interests or to focus on social problems that may not have established markets.

The connection between academia and industry had been one of the major selling points of this particular REU for these students. Some of the participants said they were not sure whether they wanted to pursue careers in industry or academia, and this experience helped them to envision what a career in industry might be like, especially for the two teams hosted at SFSU who worked on their projects in engineering company offices. They also became more aware of the different kinds of jobs that would be available to them with varying levels of education. Everyone understood that, to work in the kinds of settings they saw, they would need a graduate degree, although the Ph.D. was seen as optional.

All eight participants said that this experience convinced them that they need and, for the most part, want to go to graduate school. One said that the engineers in the company consistently reinforced the message that she should get a graduate degree. Through their REU, all had a more sharply-focused vision of what graduate school might be like, and that they would be able to be successful. None of the participants indicated a clear intention to become academic researchers, although two of the students did not rule this out. The other six said they felt certain they were focused on careers in industry. However, the REU opened up more career possibilities for several of the participants, who were unaware of all the options to which they were exposed over the summer.

The industry mentors completed evaluations of the REU participants with whom they worked. There were six response options regarding the preparedness, performance and potentials of the REU participants. All the industry mentors expressed their satisfaction of the participants. A final piece of evidence that the students had met the needs and expectations of the industry partners was that one of the companies offered internships to their REU students for the following summer.

Several of the students had no previous experience with SST - in fact, they mentioned this during their initial interviews, having applied for the REU in part because of their interest in learning about this field. As undergraduates, they had varying degrees of coursework and background knowledge of structural engineering. The two PIs used an oral evaluation rubric to score the presentations. So, there were two scores for each of the four presentations. By the time they developed their research presentations at the end of the REU, 6 of the presentation scores for depth and accuracy of content were "Proficient" (75%) and the remaining 2 were "Distinguished" (25%). Performance at these levels includes accurate and complete explanations of key concepts and presentation of supporting evidence, among other criteria. The nature of the presentations demanded high-quality graphics to accompany the talks. This aspect was scored separately, and all four presentations were judged by both scorers (100%) to have achieved the "Distinguished" level, the highest level of quality.

To conclude, the project successfully recruited a diverse and well-qualified group of participants. 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 focused on concrete, rather than abstract, distinctions. The participants' interest in continuing their studies into graduate school was solidified by their REU, both through the workshops and other learning experiences that introduced them to the process of applying for graduate study, and because their industry mentors reinforced the message that they need the knowledge and skills they would develop with advanced study. By the end of the summer experience, the participants demonstrated mastery of the content they needed to successfully complete their projects, and the professionalism and autonomy needed to work in a corporate setting.

Evaluation question 2: What were the impacts of the collaboration between academic and industry researchers on connections between the two groups?

Finding Summary: Both faculty 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. The evaluation will revisit this in Year 2 to monitor the development of these connections.

Evaluation question 3: *What kinds of research outputs resulted from the collaboration, including those of the undergraduate student participants, industry partners, and university faculty?*

Finding Summary: All the participating REU students expressed their interests to continue working on the research projects. The four presentations developed through this summer formed the basis for 4 presentations that will be delivered in 2019 Engineering Mechanics Institute conference [13].

Evaluation question 4: *What was learned about implementing productive collaborations between academic institutions and industry partners, and about creating successful undergraduate research experiences?*
A. What aspects of the project were particularly successful?
B. What aspects of the project were difficult or challenging?
C. What, if any, outcomes of the project were unexpected?

Finding Summary: As noted previously, the participant recruitment process was quite successful, with a total of 81 applicants, of whom more than 40% were female, and more than 60% were students of color, and most of whom were good candidates. The REU projects offered rich opportunities for the participants to experience a variety of aspects of research and to develop related knowledge and skills. The projects themselves allowed the participants to produce high-quality research presentations. REU participants, industry mentors, and university faculty all expressed satisfaction with the program as it was implemented. The industry partners of three of the projects involved mentors who had previous experience with the REU program, either having participated in an REU when an undergraduate, or in one case, having supervised REU students as a faculty member. This background probably had a positive impact on the quality of the students' experiences in those settings. The electronic communication between SFSU and the UofSC (videoconference links, Slack, and so forth) worked well.

The project did not run without challenges. One of the original industry partners had to drop out of the project in the months before the REU began, meaning that the project had to identify a new partner and project in a short time. Although the partnership and project that emerged turned out to be a good one, the students had to work with the company largely via electronic means. Both the students who participated in this project, and their industry mentors expressed the wish for at least some in-person time if a similar project were undertaken in the future. The projects evolved over the summer, and in some cases, it was necessary to put boundaries around what they were trying to do, so that they would not become too large. This was done successfully, but was noted as a challenge. At SFSU University, the graduate student supporting the project was very good at providing the right amount of assistance, and at being accessible, to the participants. Although the graduate student at the UofSC was responsive, he was working remotely and was not as accessible to the students.

The first year of this project was successfully implemented. Eight participants formed teams that took on high-quality research projects in four different engineering businesses.
Two recommendations emerged from the implementation review.

- When possible, projects should be situated in established engineering company offices so that the REU participants have on-site experiences.
- The involvement of graduate assistants would be highly recommended as their role is crucial for providing support to the REU students, and for making sure that the PIs and other participating faculty are not overburdened.

Acknowledgement

The authors would like to acknowledge the support from National Science Foundation EEC-1659877/ECC-1659507, the College of Science and Engineering and the School of Engineering at San Francisco State University, and College of Engineering and Computing at the University of South Carolina.

Reference

[1] Lynch, Jerome P., and Kenneth J. Loh. (2006). "A summary review of wireless sensors and sensor networks for structural health monitoring." *Shock and Vibration Digest* 38, no. 2: 91-130.

[2] Spencer, Billie F., Manuel E. Ruiz-Sandoval, and Narito Kurata (2004). "Smart sensing technology: opportunities and challenges." *Structural Control and Health Monitoring* 11, no. 4 (2004): 349-368.

[3] Housner, GWea, Lawrence A. Bergman, T. Kf Caughey, Anastassios G. Chassiakos, Richard O. Claus, Sami F. Masri, Robert E. Skelton, T. T. Soong, B. F. Spencer, and James TP Yao. (1997). "Structural control: past, present, and future." *Journal of engineering mechanics* 123, no. 9: 897-971.

[4] Spencer Jr, B. F., and S. Nagarajaiah. (2003). "State of the art of structural control." *Journal of structural engineering* 129, no. 7: 845-856.

[5] Mahin, S. A., P. B. Shing, C. R. Thewalt and R. D. Hanson. (1989). "Pseudodynamic test method-current status and future directions." J. Struct. Eng. 115 2113–28.

[6] Shing, P. B., M. Nakashima and O. S. Bursi. (1996). "Application of pseudodynamic test method to structural research." Earthq. Spectra 12 29–56.

[7] Ham, Youngjib, Kevin K. Han, Jacob J. Lin, and Mani Golparvar-Fard. (2016). "Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs): a review of related works." *Visualization in Engineering* 4, no. 1: 1.

[8] Sarkisian, M. (2011). "Tall Building Design Inspired by Nature." *Proceeding of 36th Conference on Our World in Concrete & Structures*, Singapore.

[9] Baker, W. F., Lauren L. B., Arkadiusz M., Carrion, J., and Beghini, A. (2015). "Structural Innovation: Combining Classic Theories with New Technologies." *Engineering Journal-American Institute of Steel Construction* 52, no. 3 (2015): 203-217.

[10] Jiang, Z., Caicedo, J. and Petrulis, R. (2018). "NSF REU SITE: Collaborative Research: Integrated Academia-Industry Research Experience for Undergraduate in Smart Structure Technology", *Proceedings of 125th American Society for Engineering Education (ASEE) Annual Conference & Exposition*, Salt Lake City, UT.

[11] Sdii.ce.sc.edu. (2018). Home | Smart Structures Technologies REU. [online] Available at: http://sdii.ce.sc.edu/REU_SST/ [Accessed 3 Feb. 2019].

[12] Pathwaystoscience.org. (2019). Pathways To Science. [online] Available at: http://www.pathwaystoscience.org [Accessed 3 Feb. 2019].