Board 144: Interdisciplinary & International Research Experiences in Bioinspired Science & Technology

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Interdisciplinary and International Research Experience Program in Bioinspired Science, Engineering and Technology

Abstract

Modern industry and startups, particularly in high-tech sectors, show significant growth of cross-disciplinary, cross-cultural, and cross-boundary work needs. Some cross-disciplinary areas with particular demand, now and for the future, are found at the intersection between engineering and the life sciences. Engineers increasingly need competencies in life science areas that intersect with their engineering disciplines. Engineers also must meet high-tech industry requirements of working cross-culturally, communicating effectively with all teams across the enterprise, and effectively using time and project management skills. For STEM-specific roles, young engineers are required to have data science understanding, statistics knowledge, and computational capability especially if working with big data. In response, higher education institutions (HEI) have started matching such industry needs. HEIs are initiating having students work across boundaries of sector, discipline, and identity. Students are being prepared for intersectoral collaboration and multiple career pathways in a workforce that will change more rapidly in coming years. Students are enabled to join multidisciplinary teams with people who approach problems with different methods and knowledge, and to solve problems in diverse groups in terms of culture, race/ethnicity/nationality, gender or socioeconomic status.

The International Research Experience for Students (IRES) program of NSF contributes to development of a diverse, globally engaged higher education workforce with world-class skills. Within this program, Virginia Tech (VT) in the United States, with support from the American Society for Engineering Education (ASEE), has developed a transdisciplinary, international education program in the area of bioinspired engineering. IRES graduate-level scholars from multiple fields study autonomous mobility in complex natural environments, through observation and analysis of flying/gliding rainforest animals, with the help of an interdisciplinary mentor network in Brunei, South Korea, and Singapore. So far, a single cohort of students from engineering, biology, and biophysics has completed the program in 2022. The first results show students undergo a transformative process through their interdisciplinary and international research experience in the areas of biology and engineering.

The program implements a novel paradigm to bring scholars international research experiences in STEM, especially in bio-oriented environments, in line with the need for solving transdisciplinary challenges through global collaboration and the trend towards personalized learning. To achieve this, the program introduces the following key elements to international research experiences and combines them in a novel manner: (i) focus on research-related professional development experiences that are well integrated into the IRES scholars' thesis research, (ii) leveraging of a combination of natural and academic resources in a variety of sociocultural settings, (iii) a mentor network offering students the opportunity to work with multiple mentors, selected according to students’ needs at different program stages, (iv) a modular, customizable approach to paths and schedules for individualized research experiences, (v) pervasive use of a social media many-to-many communication model to ensure coherence within each student cohort and its scientific and social communities, and (vi) constant engagement of students and mentors to accomplish professional development goals. By doing so, the program will further international collaboration, intercultural understanding, and exchange in bioinspired research.

Introduction

The growth of modern industry and startups, particularly in high-tech sectors, has led to a significant increase in cross-disciplinary [1], cross-cultural, and cross-boundary work requirements. One area of particular demand is the intersection between engineering and life sciences, and it is increasingly important for engineers in many specialties to have competencies in life sciences to complement their engineering skills. High-tech industry requirements also include cross-cultural communication, effective time and project management skills, and the ability to work in multidisciplinary teams [2]. For STEM-specific roles, young engineers need to have knowledge in data science, statistical skills, and computational capabilities when working with big data [3].

In response to such industry needs, higher education institutions (HEI) have started to adapt their programs. HEIs are preparing students to work across boundaries of sector, discipline, or identity, enabling them to join multidisciplinary teams and collaborate with people from different backgrounds. HEIs are also helping students develop problem-solving skills in diverse groups in terms of culture, race/ethnicity/nationality, gender, or socioeconomic status. These approaches prepare students for multiple career pathways in a rapidly changing workforce.

Program Implementation

The National Science Foundation's (NSF) International Research Experience for Students (IRES) program [4] aims to develop a globally engaged higher education workforce with top-notch skills. As part of this program, Virginia Tech (VT) in the United States, with support from the American Society for Engineering Education (ASEE), has created a transdisciplinary, international education program focused on bioinspired engineering. The program is designed for graduate-level scholars who will study autonomous mobility in complex natural environments, researching flying/gliding rainforest animals in the field and in the lab, with the help of an interdisciplinary mentor network located in South Korea, Singapore, and Brunei.

Beginning in 2022, the program recruits 10 US graduate students each year (30 in total over the project period) through broad outreach efforts. Participants join a 13-week summer program at VT followed by a biology immersion program in Borneo at the University of Brunei Darussalam (UBD), and finally a data analysis/engineering integration module at the Korea Advanced Institute of Science and Technology (KAIST) or the National University of Singapore (NUS). This unique program will help develop a diverse group of scholars with the skills necessary to succeed in a global workforce.

The program introduces a new paradigm that combines international research experiences in STEM, particularly in bio-oriented environments, with the goal of solving transdisciplinary challenges through global collaboration and personalized learning. To achieve this, several key elements are incorporated into the international research experiences in a unique way. These elements include a focus on research and professional development that is integrated into the IRES scholars' thesis research, a combination of natural and academic resources in various sociocultural settings, a mentor network that offers students the opportunity to work with multiple mentors based on students’ needs, a customizable approach to paths and schedules for individualized research experiences, pervasive use of social media to ensure coherence within

each student cohort and its scientific and social communities, and constant engagement of students and mentors with ASEE support to achieve professional development goals.

The program aims to foster international collaboration as well as intercultural understanding and exchange, while also achieving the scientific goal of advancing cross-disciplinary understanding of autonomy in complex natural environments. The result will have a transformative impact on addressing societal challenges related to environmental monitoring and cleanup, precision agriculture and forestry, and engineering novel forms of autonomous transportation based on bioinspired research.

First results

The specific objectives of the program have been to (i) provide international and interdisciplinary research experience for scholars, (ii) advance cross-disciplinary understanding of biological model systems for autonomy in complex environments, (iii) provide intercultural experiences for the IRES scholars, and (iv) disseminate resulting research to the international scientific community as well as local stakeholders and the public in Brunei.

Ten US students have participated in an international research experience program that started with multiple virtual meetings during the spring 2022 semester, then an in-person preparation week at Virginia Tech in the US, followed by 11 weeks of research in Brunei, and additional research work at the National University of Singapore (NUS), the Korea Advanced Institute of Science and Technology (KAIST), or in Brunei. During their stay in Brunei, the students had repeated opportunities to experience Borneo's biodiversity firsthand, in a 130-million-year-old primary rainforest, Ulu Temburong National Park, and through multiple field trips to Brunei's other natural habitats especially its tropical heath and peat forests.

The IRES scholars were teamed up with local buddies (University of Brunei students), and participated in short program, day-to-day activities such as local meals that were designed to expose them to Brunei's diverse cultures (Malay, Chinese, indigenous cultures). Similarly, the IRES scholars were teamed with local students in Singapore and South Korea, and joined them in activities designed to expose them to local culture.

In the field in Borneo, the IRES scholars successfully set up synchronized arrays of high-speed video and ultrasonic microphones as an experimental platform for their research. The high-speed array had been previously constructed at Virginia Tech, with support from an NSF MRI grant, then shipped to Brunei. The IRES scholars successfully assembled this array in Borneo, integrating it with an array of 32 ultrasonic microphones. The completed instrument constitutes a unique experimental capability that has provided the IRES scholars with animal motion data sets unmatched in quality as well as quantity. Combined with deep-learning methods for data processing and analysis, this experimental ability will allow the IRES scholars to investigate the linkage of biosonar sensing and flight behaviors in bats.

In the summer, the IRES scholars in collaboration with their local buddies made use of this experimental capability to record about 80 flight sequences, each lasting about 5 seconds, from different bat species while keeping data quality standards set by the needs of further analysis. This data set is unprecedented in its coverage of different temporal-spatial resolution of these

animals. The IRES scholars completed the initial pre-processing of this data set, which has since been used to develop a deep-learning approach to automatically eliminate frames that show only a partial bat or no bat. This data pre-processing will enable the use of automated methods for further data analysis. The pre-processed data is currently being used to test deep-learning methods for tracking the kinematics of a flying bat and reconstructing the three-dimensional shape of a flying animal with a high resolution.

In addition to capturing the animal recordings, scholars revised and partially reimplemented a biomimetic, flapping-flight robot to collect a very limited set of pilot recordings. Insights from experimentation with this early-stage flapping-flight robot are currently being used by an undergraduate capstone design team at VT and UBD to make a number of substantial improvements in the flapping-flight robot design. The new prototype will be tested in the flight tunnel cycle (Summer 2023) of the IRES program. For the ultrasound array recordings, a small pilot data set has been collected that will form the basis for further adjusting microphone array hardware and developing the array. In the field, a biomimetic sonar robot has been used to collect a substantial set of ultrasonic echo data from complex natural habitats in Brunei. As with the work on the flapping-flight robot, the experiences of the IRES scholars with this hardware have been used by an undergraduate senior design team (where) to develop a new version of the sonar robot, that will be tested in Brunei by the next cohort of IRES scholars. In both cases, the experiences passed along by the IRES scholars to the respective senior design teams have pertained to a wide range of issues related to functionality, reliability, and usability. Graduate students in the IRES program have been in touch with the undergraduate students working on the new designs throughout the design cycle, to ensure that relevant information was available whenever it was most useful. Through their field work, the IRES scholars have been able to characterize bat fauna at three field sites: Andulau Forest Reserve (on the border of Tutong and Belait Districts), Mata Mata (Bukit Silat Trail, Brunei-Muara District), and Kiudang District.

The experience of the IRES scholars, as well as that of their hosts in Brunei and their US advisors, has been evaluated using pre- and post-departure evaluations. The pre-departure survey of the graduate students included collection of basic demographic information, as well as questions aimed at establishing a baseline of their research skills and international/intercultural competencies. The IRES scholars group was found to be much more diverse than the typical population of US engineering graduate students: two of the scholars were African American, including one from an Historically Black College or University (HBCU), Virginia State University (VSU), and one student identified as multiracial. In addition, other than the first three mentioned, three of the IRES scholars were women. In their exit interviews, most IRES scholars indicated that they had enjoyed the international environments and the hospitality of the local students, especially in Brunei where most of the international program has been located in the past cycle.

The evaluators received positive feedback from the collaborating faculty in Brunei, who reported that the IRES program has been beneficial to them in terms of gaining knowledge and access to equipment brought by the IRES scholars and the US faculty. The program has also contributed to internationalization and research development at all the universities involved. The program has generated interest from various international stakeholders including academia, government, and business, as well as the general public. NUS and KAIST have expressed interest in sending their

own students to Brunei to conduct research alongside IRES scholars in the summer of 2023, while the US Embassy to Brunei has supported the collaboration with a Fulbright specialist position in 2022 and is preparing to do so again in 2023.

The IRES scholars have gained new research skills and perspectives beyond their own fields, such as exposure to biodiversity and firsthand experience studying flying and gliding animals in the field and lab. Scholars have also learned experimental techniques using the latest technologies (e.g., high-speed video, ultrasonic arrays, biomimetic robots) and data analysis techniques (especially Machine-Learning-based) that have expanded their skill sets. The program has had a measurable impact on the scholars' intercultural competence, with their self-reported intercultural competence being strong at the end of the program. They have gained knowledge, skills, comfort, and awareness in relevant areas and are knowledgeable about Brunei's culture. Language skills were not part of this project, since the University of Brunei uses English as the main language and English is almost universally spoken in the country. Additionally, most of the scholars felt they had gained he necessary intercultural skills to conduct research abroad after completion of the program.

The research of the IRES scholars has begun to produce data sets on sensing and motion in dexterous flying/gliding mammals, along with deep-learning analysis methods that could be potentially transformative in the interdisciplinary area between biology and engineering. This is due to the quantity and quality of the biological data obtained, and the potential of the deep-learning methods to 1) process large amounts of data and extract patterns that could bring new insights about the biology of animals that move through complex natural environments, as well as 2) provide new approaches for bioinspired, human-designed systems that could do the same. Autonomous mobility in complex natural environments is a fundamental capability extremely relevant for several engineering disciplines covering areas such as precision agriculture and forestry, environmental surveillance and cleanup, disaster rescue, and national security. The work of the IRES scholars could impact all these critical engineering disciplines.

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