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Development of Multidisciplinary, Undergraduate-Led Research Program in Soft Robotics

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Abstract

This Work in Progress (WIP) paper presents a one-year pilot of a mentored research program for freshmen and sophomore level undergraduate engineering students. Participation in undergraduate research increases confidence and awareness of STEM opportunities. Approximately 45% of undergraduate engineering students at the University of Illinois Urbana Champaign (UIUC) participate in research on or off campus. Comparatively, in 2019 less than 1% of students from the three cohorts of the Academic Redshirt in Science and Engineering (ARISE) program at UIUC participated in research. Based on student initiative to gain research exposure, a group of students, faculty, and staff co-developed an undergraduate research mentorship program focused on work in the field of soft robotics. The program is aimed at providing exposure to research within the first undergraduate years. The goal is to involve students in the culture of research - publishing papers, attending conferences, and mentoring other students, all shown to have positive outcomes for undergraduate students and promote further exploration of research opportunities. To do so, we created a cohort-based, funded research opportunity for students from the ARISE program at UIUC. Here we describe the development, structure, and outcomes of the pilot year of an all-undergraduate soft robotics research program.

Introduction

Participation in undergraduate research opportunities increases understanding, confidence and awareness of opportunities in STEM fields [1]. In a national study, students' desire to pursue a PhD increased by ~29% after performing undergraduate research [1]. Approximately 45% of UIUC Engineering undergraduate students participate in research on or off campus. Comparatively, less than 1% of students from the three cohorts of ARISE program have participated in research. To help close the undergrad research gap between ARISE students and their peers, we proposed developing a mentored research program, designed for students to gain an authentic research experience in a supportive environment. This experience is intended to build STEM confidence, provide paid research opportunities, and serve as a launch pad for these students into larger research groups. This program gives students across disciplines an opportunity to develop technical skills in soft robotics, a broad field of study that uses fundamentals from many engineering disciplines. We present results from a pilot year of the program aimed at reducing the disparity in undergrad research experiences for ARISE students.

In years one and two of the ARISE program, students have not yet declared an engineering major but are exploring options. Due to the financial barriers or lack of confidence, students from underrepresented groups tend to choose part-time work on campus over research or STEM related experiences [2]. For this reason, these students historically miss out on opportunities to explore STEM career paths and possibilities of advanced degrees. The program described here, provided a funded research experience, to maximize ARISE students' engineering potential and ultimately their success and graduation from UIUC.

Students who participate in the "culture of research" - publishing papers, attending conferences, and mentoring other students, are the most likely to realize the positive outcomes of the experience [1]. Sustained engagement of longer than twelve months also increased positive outcomes. High-impact practices, such as undergraduate research, have had a pronounced impact on the experiences of underserved students [2]. We aim to create an environment where students can build a foundation in the culture of research early in their undergraduate careers. In the pilot program students completed authentic research scholarship and innovated in the field of soft robotics. To ensure high impact engagement, students attended conferences and prepared results for conference presentations, and mentored students.

Soft Robotics Focus

When developing this program, we asked how can hands-on, human centered design projects impact students' abilities to build technical competencies and confidence in engineering? Soft robots replace traditional hard components with compliant materials and flexible electronics [3]. The research area has several attributes that make it amenable to undergraduate participation. Soft robots can be made from common, low-cost materials [4]. The nascent field allows for novel contributions from young students. The field is highly interdisciplinary, drawing on traditional mechanical and electrical principles to use new materials for human-centered, biomedical applications [5]. Students from many disciplinary backgrounds can bring their engineering foundation to the group and contribute in unique ways.

Students in years one and two of the ARISE program, have not yet declared an engineering major. Soft robotics allows these students to experience hands-on projects relevant to multiple fields. In this program students from diverse backgrounds and intended majors, collaborate to develop biodegradable actuators and testing platforms toward implantable, biocompatible robotic devices. Co-author Golecki, a bioengineering faculty member oversees the work, guiding students while providing space for experimentation. Students begin with onboarding activities including safety training, actuator fabrication, 3D printing workshops, CAD training, and an introduction to microcontroller function. With these foundational skills, students work towards technical goals with freedom to explore different aspects of the multifaceted project throughout the semester. These activities allow students to develop translatable skills while building foundational components used in soft robotic devices.

Formation of the Student Team

Previously, Golecki ran a small soft robotics research group for high school students [6]. The students developed novel advances in the field of soft robotics including gelatin based actuators [7], and a glove to teach nuanced hand movements in the art of ceramics on the potter's wheel [8]. These students presented their work at conferences and co-authored peer reviewed publications on their work. Students from this program overwhelmingly matriculated to engineering majors and some arranged summer internships for themselves in university research groups afterward. The impact the research experience had on students was profound and Golecki used this experience as inspiration for the program presented here. In this project, freshman and sophomore undergraduates were recruited from the ARISE program at UIUC.

Each year, the ARISE program admits 25 Pell-eligible students who applied to engineering majors at UIUC. These students have excellent high school grades but typically attended low-resourced schools and consequently lack secondary education preparation. From a University of Washington Center for Evaluation & Research for STEM Equity study, UIUC ARISE students lack confidence in science and engineering and are more likely than their non-ARISE peers to anticipate financial barriers to completing their degrees. Due to the financial barriers and lack of confidence, ARISE students often choose part-time work on campus over research or STEM related experiences. ARISE students are missing out on opportunities to explore STEM career paths and possibilities of advanced degrees.

In year one, six ARISE students from diverse backgrounds, planning to pursue different majors participated in the program by collaborating to develop robotic devices during the 2020-2021 academic year. Golecki, faculty mentor for the group, designed projects for the students to choose from that are novel and framed such that portions of the project can be reasonably completed in one semester. In addition to the faculty mentor and students, Harrison-James a mentor from the business school lead professional development activities each week in group meeting. Students worked in the lab up to 6 hours per week during the semester building polymer actuators and a physiologically relevant dynamic testing setup (Figure 1). The cohort experience formed a supportive community for students inside and outside the lab. In the lab, students collaborated to develop pneumatic and cable-driven biopolymer actuators and testing platforms to inform biocompatible and wearable robotic devices. In addition to lab work, the group met weekly for structured mentoring sessions, performed outreach in the college of engineering and attended external conferences and workshops throughout the year.

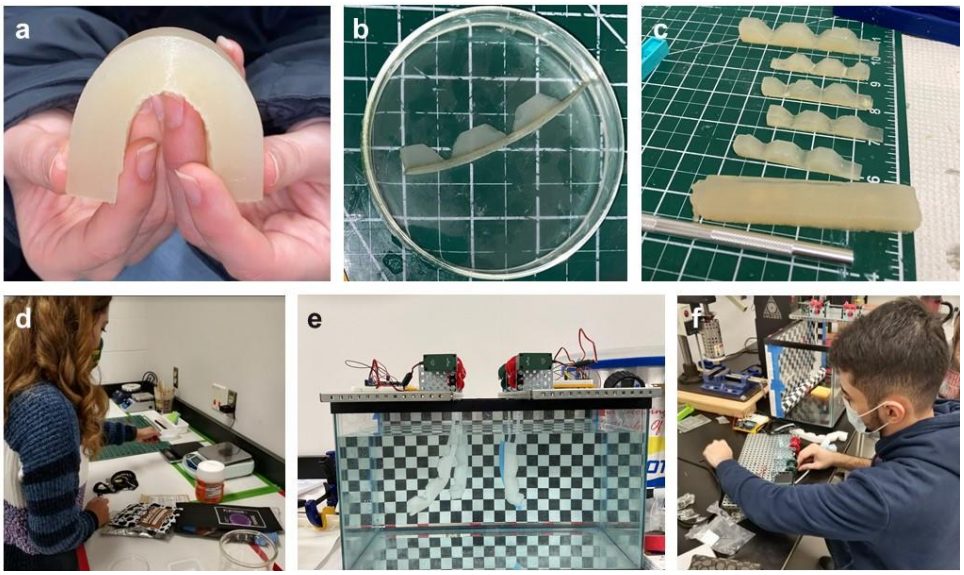

Figure 1. Student lab work including (a) a student demonstrating hydrogel behavior during bending, (b) hydrogel-based actuators, (c) multiple molds of hydrogel actuators, (d) student researcher prepping prototyping materials, (e) silicone actuators in a dynamic test rig developed by students, (f) student researcher building test rig.

Weekly Group Meeting

In addition to technical, laboratory skills, students were provided a variety of workshops related to research and their professional development. Workshops were delivered by subject-matter experts, further facilitating networking and community building. In weekly group meetings, students presented progress on goals, discussed current literature, practiced career-readiness skills and brainstormed independent projects.

Progress reports. Each week students prepared a one slide progress report. A slide template was distributed with three prompts (see Figure 2):

- *What did you do this week?*
- *What question do you have?*
- *What will you do next week?*

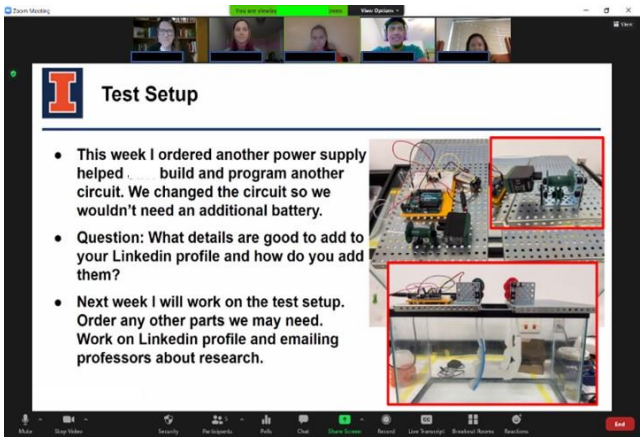

Figure 2. Zoom-based weekly group meeting presentation by one student.

Workshops. Technical and professional development workshops were held during select weekly meetings. Workshops were intended to map to specific project activities such as actuator fabrication, literature searches, abstract preparation, and networking. A list of workshop topics is listed in Table 1.

Table 1. Workshop topics

Topic	Delivered by
Lab Safety Training	Faculty mentor
Literature search/library resources	Engineering Librarian
3D printing workshop	Prototyping lab manager
Autodesk Fusion 360 tutorial	Autodesk representative
Career readiness/ professionalism/networking	Business mentor
Scientific Writing	Writer's Workshop
Networking for research positions	Office of Undergraduate Research

Technical Communication

Students in this program experienced authentic research scholarship and innovated in the field of soft robotics. An essential part of the culture of research is attending conferences and presenting work. Although many conferences were held in a virtual format due to the COVID-19 pandemic, students were able to present at two discipline-specific virtual conferences during the 2020-2021 academic year (Biomedical Engineering Society Meeting, IEEE RoboSoft Conference). In preparation for these conferences, the students engaged in multiple internal speaking opportunities. In addition to speaking weekly at group meeting, students presented on their research at outreach events hosted by the Grainger College of Engineering and at the Institute for Diversity, Equity, and Access. Students cited their development in areas of public speaking among the most significant gains they made during the program and the most useful gains connected to their careers.

Assessment and Evaluation

Student outcomes were evaluated by analyzing results of the Undergraduate Research Student Self-Assessment (URSSA) survey. As part of this program, we administered the URSSA survey at the end of the first semester (UIUC IRB #21284) [9]. This scale developed by University of Colorado Boulder evaluates skills-based student outcomes of undergraduate research experiences to identify students' perceptions of gains from engaging in research. While the survey response was positive, due to the small size of the current cohort (n=6 students), we chose to use the survey as a reflection tool for program organizers (faculty and staff). See below for reflections on the pilot program, based in part on the URSSA survey.

Results and Reflection

One aspect of the pilot that could not be controlled for is the ongoing COVID-19 pandemic. News of internal funding for the program came in March 2020. We began the program when students returned to campus in Fall 2020. Students were allowed access to the laboratory with COVID-19 restrictions that included regular testing, mask wearing, and social distancing. Weekly meetings were held virtually on Zoom. While the pandemic made this experience particularly challenging, the students were enthusiastic for an in-person experience and were able to complete their work safely. As mentioned, travel restrictions limited access to conferences and interaction with many other lab groups. Despite the challenges of the pandemic, we were able to realize gains in research participation and student reported gains in research skills.

Our primary goal was research engagement. Over the course of the year, we saw research participation for students from three cohorts of ARISE increase from 1% (2019) to 11% (2021). This includes the dix students enrolled in this pilot, but also students in ARISE that sought research opportunities independently through peer influence. Additionally, from URSSA results after Fall 2020, 80% of participants reported being “much more likely” to pursue a masters degree than prior to doing research and 50% reported being “much more likely” to pursue a PhD. The greatest gains were seen in working independently, collaborating with others, and figuring out the next step in a research project. Students reported spending time thinking creatively about a project, trying out new ideas on their own, and feeling responsible for the work. Based on the data, gains were weakest in preparing a scientific paper, preparing a poster, using statistics to

analyze data. Responses to open ended questions in the URSSA survey are summarized in Table 2. In open ended responses, students reported not interacting with scientists from other schools. After this one student reached out to the author of a paper they had questions about. This led to a collaboration with that group. Additionally, the students had an opportunity to attend and share their research at an Undergraduate Workshop at the IEEE Robosoft Conference in April 2021 where they met graduate students in this field as well as other undergraduates with an interest in soft robotics research.

Table 2. Open ended responses from URSSA survey.

Open ended survey question	Example Responses
Please comment on any aspects of your experience in this research program.	• "This research group is amazing, and I love everything about it." • "An excellent experience overall." • "It was all great being able to learn and work with other members to do research." • "Excellent group and amazing mentors who have showed me ample amounts of opportunities and didn't know existed."
Compared to your intentions before doing research, how likely are you now to enroll in a graduate program leading to an advanced degree?	• "I am more inclined to do research in the future, and I am more likely to enroll in a graduate program" • "Much more likely to enroll in a graduate program leading to an advanced degree" • "I think the research helped me to put into perspective the potential work I could see myself doing in the future. I was already hoping to eventually apply and go to graduate school, but I suppose I would be more likely now considering I really liked the work we did." • "Before I was unsure if I wanted to enroll in a graduate program but now I plan to." • "I will likely enroll for a masters" • "I will most likely enroll in a graduate program because of this opportunity."
How did your research experience influence your thinking about future career and graduate school plans? Please explain.	• "Research allowed me to see how school relates to real life and that there is more to school than homework. Because of this I am more inclined to participate in something similar in grad school." • "I am considering a PhD in either mechanical engineering or engineering education" • I think it really motivates me more to become an engineer by demonstrating the different types of work I could expect in my own field." • "My professor who conducts our research earned her PhD and seeing all that she has accomplished has inspired me to pursue a higher degree." • "I am interested in doing more research in the future" • "This experience has shown me the importance for further education so I plan to pursue a masters after my undergrad and then work in industry. I do see myself teaching later down the line though."
What would have made your research experience better?	• "I wish I did more of the recommended networking and talked to other professors." • "I need more experience before I can say." • "Getting to see what other research groups are doing." • "Nothing could have made the experience better."
What would improve the undergraduate research program, overall?	• "Nothing other than pandemic related issues." • "More workshops to each us important skills." • "Bringing in more students to allow for mentorship roles." • "More mentors to build initial accountability and answer questions between meetings."

Based on the URSSA survey and candid student reflections, we offer a list of recommendations for other faculty, programs, or institutions interested to create similar programs.

Reflections from the pilot for adapting at other institutions.

- The cohort experience was a benefit to students. They enjoyed working alongside peers in this new effort.
- The students had an interest to interact with other research groups or to understand other research available on campus. As mentioned above, our goal is for a subset of students to stay on as mentors for new cohorts, and others to move on to research assistant positions in larger research groups on campus.
- Soft robotics allows students to gravitate toward their own interests from electronics, to soft materials, to CAD and 3D printing.
- Keeping a log of weekly meeting slides allowed students to develop an end of semester presentation and gave them "an enormous sense of pride" to reflect on their work from the semester.
- Students were eager to take on a mentoring role. This allows us to engage more students in the program.
- The biggest change that we will implement in year two of the program based in the URSSA survey is to facilitate students leading the conference abstract and paper writing and poster preparation.

Future Considerations

Many of the positive attributes of such a program can only be measured in a longitudinal study of the students' trajectory. In addition, while many have studied recruitment of women and other groups underrepresented in engineering to electrical and mechanical engineering majors, numbers have stagnated over the last decade. We hypothesize that the human-centered applications of soft robotics may align with agency beliefs and will use the Critical Engineering Agency framework [10] as a lens through which to evaluate student participation in this program. Within UIUC, we anticipate this program to be a model for other research groups to set up a mechanism for underrepresented students to engage in research. In addition, smaller institutions (community colleges or undergrad only institutions) may use this program as a model for similar experience for their students, promoting a diversity of researchers engaging in soft robotics and considering pathways programs or graduate education. We see mentored research experiences as one component necessary to addressing the disparity in persistence and pursuit of graduate degrees for students from groups underrepresented in STEM.

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References

[1] S. H. Russell, M. P. Hancock, and J. McCullough, “THE PIPELINE: Benefits of Undergraduate Research Experiences,” *Science*, vol. 316, no. 5824, pp. 548–549, Apr. 2007, doi: 10.1126/science.1140384.

[2] G. D. Kuh, *High-impact educational practices: what they are, who has access to them, and why they matter*. Washington, DC: Association of American Colleges and Universities, 2008.

[3] F. Ilievski, A. D. Mazzeo, R. F. Shepherd, X. Chen, and G. M. Whitesides, “Soft Robotics for Chemists,” *Angew. Chem.*, vol. 123, no. 8, pp. 1930–1935, Feb. 2011, doi: 10.1002/ange.201006464.

[4] N. G. Cheng *et al.*, “Design and Analysis of a Robust, Low-cost, Highly Articulated manipulator enabled by jamming of granular media,” in *2012 IEEE International Conference on Robotics and Automation*, St Paul, MN, USA, May 2012, pp. 4328–4333. doi: 10.1109/ICRA.2012.6225373.

[5] M. Cianchetti, C. Laschi, A. Menciassi, and P. Dario, “Biomedical applications of soft robotics,” *Nat. Rev. Mater.*, vol. 3, no. 6, pp. 143–153, Jun. 2018, doi: 10.1038/s41578-018-0022-y.

[6] L. A. Wilson, “Food for thought—edible soft robotic candy actuators,” *MRS Bull.*, vol. 43, no. 5, pp. 328–329, May 2018, doi: 10.1557/mrs.2018.112.

[7] A. N. Sardesai *et al.*, “Design and Characterization of Edible Soft Robotic Candy Actuators,” *MRS Adv.*, vol. 3, no. 50, pp. 3003–3009, Oct. 2018, doi: 10.1557/adv.2018.557.

[8] A. H. Greer *et al.*, “Soluble Polymer Pneumatic Networks and a Single-Pour System for Improved Accessibility and Durability of Soft Robotic Actuators,” *Soft Robot.*, p. soro.2019.0133, Jun. 2020, doi: 10.1089/soro.2019.0133.

[9] T. J. Weston and S. L. Laursen, “The Undergraduate Research Student Self-Assessment (URSSA): Validation for Use in Program Evaluation,” *CBE—Life Sci. Educ.*, vol. 14, no. 3, p. ar33, Sep. 2015, doi: 10.1187/cbe.14-11-0206.

[10] A. Godwin, G. Potvin, Z. Hazari, and R. Lock, “Identity, Critical Agency, and Engineering: An Affective Model for Predicting Engineering as a Career Choice: Identity, Critical Agency, and Engineering Careers,” *J. Eng. Educ.*, vol. 105, no. 2, pp. 312–340, Apr. 2016, doi: 10.1002/jee.20118.