CAREER: Supporting Professional Formation of Robotics Engineers through a Human-Centered Design Approach

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Abstract

Industry is experiencing significant growth in robotics, manufacturing, and related technical jobs. However, engineering programs traditionally aligned with robotics are not growing to meet this workforce need. Current strategies to attract more students to robotics-aligned engineering majors have not successfully altered these trends. This led us to ask, how can pre-college robotics curricula be reimagined to positively impact students' perceptions of engineering majors and their belonging in robotics through emotional connection to curricular applications? This CAREER project uses an integrated research and education approach to disrupt traditional robotics education with a science-integrated, human-centered soft robotics curriculum and career resources. Successful pathways for students to robotics-aligned engineering majors are understudied. This project aims to teach applications of engineering that are not currently addressed in traditional pre-college robotics, improving upon the current state-of-the-art. New knowledge in methods to measure human-centered engineering design self-efficacy and opportunities for affective learning with robotics are proposed to improve existing curricula. This integrated research and education project aims to produce a framework by which educators can teach engineering concepts in science to (1) change perceptions of robotics applications, and (2) empower more students to develop engineering identities and robotics career interest in high school. A rich understanding of the alignment of human-centered design and hands-on robotics projects may promote the development of programs that can disrupt misconceptions of STEM careers that currently exist for some in high school. This paper details the development of educational resources to support robotics education and early steps toward human-centered design self-efficacy validation. Altogether, this paper shares outcomes from an engineering education CAREER award in supporting robotics workforce development.

Background on Human Centered Design and Soft Robotics

The increase in robotics applications in engineering makes growing the population of robotics engineers a critical need. Despite significant growth in robotics and related technical jobs [1], the United States is not producing enough engineer graduates to meet this need [2]. Current strategies to attract more high school students to robotics-aligned engineering majors have not successfully increased enrollment [3]. The presence of technology in the classroom alone, without supporting educational philosophy, learning environment, and curriculum, is not sufficient to impact learning and engagement [4]. This led us to ask: *How can pre-college robotics be reimagined to positively impact students' perceptions of engineering majors and their belonging in robotics careers through emotional connection to curricular applications?* To answer this, we proposed a project to disrupt traditional robotics education with a fundamental shift to human-centered soft robotics (SoRo) in HS science classes with curricula and career resources. Our prior work showed that some students believe that robotics work is primarily "long mathematical codes" [5]. We propose that SoRo, which leverages low-modulus materials for wearable and bioinspired technologies, can broaden narrow perceptions of robot applications and attract students to the robotics workforce.

SoRo work is rooted in Human-Centered Engineering Design (HCED) [6], where human users' comfort and safety are at the core of technical designs. For the context of this project, we define HCED as an iterative design process to identify unmet user needs to collaboratively and systematically develop engineering solutions [7], [8]. SoRo may also align with engineering agency beliefs [9], a construct from the Critical Engineering Agency (CEA) framework [10] that encompasses students' thinking regarding using engineering to better society [11]. Engineering agency beliefs have been used to explain why some students choose biomedical and environmental engineering majors [10], and can be a stronger influence on developing engineering identity than math or physics identity [11]. We believe that our HCED SoRo curricula [12], [13], [14], [15], [16] can foster students' views of robotics as a tool to enact change in their communities. We hypothesize this will promote engineering agency beliefs, thereby strengthening engineering identities, and HCED self-efficacy, attracting more students to robotics and engineering careers. Preparing for the future of robotics will require a multifaceted approach that equips teachers, families, and students with resources to holistically support students choosing robotics-related careers.

Theoretical Frameworks

Social Cognitive Career Theory is a lens through which to study Robotics Career Interest. This project relies on prior research in Social Cognitive Career Theory (SCCT), whose central tenet is that career interests develop through experiences and as a function of self-efficacy expectations [17]. Self-efficacy is defined as a person's belief or confidence in their ability to perform a given behavior [17]. A positive relationship between career self-efficacy and interests has been documented across several studies [18], [19], [20], [21]. SCCT is a well-established theoretical framework to understand the mechanisms through which individuals interact with cognitive and contextual factors to shape career interests and academic or career choices. Our long-term goal is to validate an existing measure of HCED self-efficacy for K12 to reveal students self-beliefs related to robotics and to understand their HCED-robotics interests. This study challenges the paradigm that robotics is only for those with preexisting math or coding skills. In this project we use SCCT to capture dynamic mechanisms through which students interact with cognitive (e.g., HCED self-efficacy, outcome expectations, and career interest) and curricular/extracurricular supports and barriers (e.g., science integrated curriculum, peers, family) that play a role in shaping career plan development [22]. We hypothesize that, as students gain HCED robotics self-efficacy and interest, they will engage in and set robotics-related goals.

Critical Engineering Agency (CEA), a theoretical framework adapted from the earlier Critical Science Agency [23] has been used to understand students' subject-related identities and agency beliefs, precursors to developing engineering interest [10]. CEA combines subject-related identity constructs (interest, performance/competence, recognition) with engineering agency beliefs. Engineering agency beliefs of students enrolled in engineering majors were strengthened by hands-on projects early in college curricula [24]. Identities and agency beliefs can be evaluated as 'Person Inputs' to SCCT. In this study, we proposed two dependent variables: identity and self-efficacy, hence our use of CEA and SCCT together. We believe that identity without HCED self-efficacy and self-efficacy without engineering identity are not enough to encourage students to pursue robotics careers. We argue that the interplay between both variables makes SoRo a unique approach to promote robotics careers.

Soft Robotics Curriculum

The HCED SoRo curriculum [14] was developed to connect scientific concepts to robotics [25]. In this curriculum we emphasize applications of SoRo in the healthcare using biocompatible materials [26], [27], miniaturizing actuators for medical device design [28], [29], and agriculture and marien safety [30] are emphasized to strengthen links between SoRo and agency beliefs central to this project. The curriculum is aligned with NGSS standards [14]. Illinois is one 44 states that has adopted NGSS, therefore alignment with NGSS is enhances broad applicability of findings. Each science module consists of five 50-minute class periods, including time for cleanup and transitions using skin-safe materials.

We recently provided our perspective on how soft robotics can present a human centered viewpoint of robotics to expand the robotics workforce [31]. We've conducted this work in elementary [13], [32], middle [33] and high school [12], [34], [35] classes and outreach events. Efforts to engage students in HCED projects can also benefit students when they matriculate to engineering programs where HCED is embedded in coursework [15], [36], [37]. Recently, we used engineering agency belief measures in a mixed-methods study of one 11^{th} grade science class. In this study, we measured changes in high school students' agency beliefs and engineering identity in response to SoRo in physics [25]. Data analysis shows a significant increase ($p<0.001$) in both girls' and boys' agency beliefs after engaging in the introductory SoRo curriculum, showing that the curriculum may help all students see robotics as a pathway to serving their communities with engineering. Introducing the curriculum in 11^{th} grade showed that some students' career ideas are already formed, while others' may change. This data inspired our develop of career conversation cards (work on going) and longitudinal data collection to understand how student career attitudes change over time because of the three-year curriculum (work on going).

We began delivering soft robotics curricula at a public high school in the Midwestern United States. This semester, we delivered a full course in computational approaches to soft robotics where students used Autodesk Fushion230 and Blender for design. Additionally, students used tools created to facilitate design work in Matlab and Python (used via Google Collab). Students then built soft robots based on their designs and analyzed performance by building test rigs in Arduino controls, using OpenCV computer vision software, and python for data visualization. Students presented their work at the University of Illinois Urbana Champaign's Undergraduate Research Symposium in the high school category. Data collection to understand perceptions of robotics and robotics-related careers is ongoing.

Future Outlook

Soft robotics serves as an alternative platform for teaching robotics and design principles to K12 students through biomedical applications, hands-on prototyping, and career exposure. Early data shows changes in agency beliefs with longitudinal data collection ongoing. Though this curriculum focuses on soft robotics, its structure, rooted in HCED, can be adapted to meet the interests and needs of students in other design-focused areas of engineering.

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