Building a Robust Bioeconomy Workforce: A Policy Approach to Bridging the Gap in Undergraduate Experiential Learning

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Executive Summary: The U.S. bioeconomy is rapidly expanding and is expected to open the door to over a million jobs by 2030. Experiential learning, also known as "learning by doing", is a critical component of education and training for workers entering the bioeconomy. To prepare students with the skills they need to succeed in the bioeconomy workforce, we recommend that the NSF create a center to develop experiential learning opportunities in biotechnology and biomanufacturing in four-year undergraduate degree programs. These recommendations include prioritizing project-based learning labs and providing coordination and financial support for industry internships that enable students to tackle industry-relevant problems with hands-on projects.

I. Introduction

The field of engineering biology is enabling the development of innovative technologies and sustainable alternatives for biomedicine, manufacturing, agriculture, and environmental remediation. The bioeconomy–of which engineering biology is a core part–is projected to contribute up to $4 trillion yearly to the global economy in the coming decades and could support 1.1 million jobs in the United States alone (Chui et al. 2020). To realize the transformative potential of engineering biology, the United States needs to train a workforce that can meet growing demands. Central to achieving this is prioritizing equity and sustainability to overcome systemic barriers and ensure equal opportunities. President Biden called attention to this need in a recent Executive Order, directing agencies to develop a plan to expand access to education and training opportunities in biotechnology and biomanufacturing (The White House 2022). The plan, released earlier this year, recommended bolstering programs that center experiential learning to train both technical and professional (soft) skills. However, these recommendations were primarily focused at community colleges, with less focus toward improving access to such programs at 4-year Bachelor's institutions (The White House 2023).

Experiential learning, or "learning by doing," is a method of teaching that requires students both actively engage and self-reflect on the learning experience to gain a better understanding of the knowledge (Kolb 1984). Common examples of experiential learning include on-the-job training, laboratory classes, research theses, or internships.

Experiential learning varies in form, focus, and depth depending on training goals and needs but both the technical (at the bench or *in silico*) and professional/soft skills (communication, teamwork, etc.) gained from in-the-lab experiences are key to securing a job in the engineering biology industry post-graduation.

However, not all 4-year Bachelor's graduates receive the necessary experiential learning training for the technical and professional skills required of the roles they are expected to fill. For example, one survey conducted by the Mid-Atlantic Biology Research and Career Network found that 55% and 45% employers identified professional/soft and technical skills deficiencies among applicants for entry-level jobs (Thompson et al. 2018). In another survey of life sciences companies, 31% of respondents said that the lack of applicants with the necessary scientific or professional skills was a significant obstacle to hiring (MassBioEd 2019). This finding was further affirmed by our own engagement with industry and academic subject matter experts in the Engineering Biology Research Consortium, a non-profit, public-private partnership dedicated to advancing engineering biology to address national and global needs.

While 4-year institutions do offer or encourage experiential learning opportunities, these are often extracurricular and underutilized. Senior theses or capstone projects are common mechanisms by which experiential learning is incorporated into Bachelor's degree programs; however, an NSF survey found that, while over 80% of engineering graduates participated in a "culminating senior experience," only 53% of biological and biomedical sciences graduates did the same (NCES n.d.). Internships and undergraduate research experiences provide the most relevant hands-on training for students, yet that same survey found that only 28% and 39% of biological and biomedical sciences majors participated in internships (paid or unpaid, respectively), and fewer than half reported participating in a research project with a faculty member. In addition, these forms of extensive experiential learning are not always accessible to all students, resulting in inequitable educational training. In another survey of over 1,500 students across 5 universities, 64% of students who did not participate in internships reported that although they wanted to, they faced barriers that included economic considerations (needing to work a full- or part-time job or insufficient internship pay) and heavy courseloads (Hora et al, 2019). Other studies found similar barriers to participation for both internships and undergraduate research opportunities, which are amplified for underrepresented or marginalized students (Thompson, Perez-Chavez and Fetter 2021; Wolfgram, Vivona and Akram 2021; Shaw and Bergson 2022). Finally, there has been a shift away from the methods-based, "cookbook" style biology laboratory classes that are traditionally required in biological sciences toward classes that better replicate authentic research experiences (National Research Council 2003). Traditional, methods-based labs engage students at a low level intellectually and inaccurately represent the process of scientific research (Brownell et al. 2012). As a result, a substantial fraction of students, particularly those from underrepresented groups, are exiting with a Bachelor's degree without the technical and professional skills gained through extensive experiential learning experiences that are required to secure a job in industry.

Federal funding has played a pivotal role in coordinating technical and professional education for the biotechnology workforce at primarily two- and four-year institutions. Most recently, this coordination has come via the NSF-funded InnovATE*BIO* network which has over 100 members that primarily offer 2-year biotechnology-relevant certificates or degrees (InnovATEBIO National Center for Biotechnology Education 2019). Notably, a requirement for membership in the InnovATE*BIO* network is that programs provide experiential learning in the form of research or industry internships that enable students to work in a real laboratory setting, underscoring the importance of this type of training. Through this and similar efforts, community colleges have streamlined the training necessary for jobs in the bioeconomy, such that employers are hiring students out of the programs even before they graduate (California Community College's 2022). Such community college programs provide key models for how industry-relevant experiential learning can be successfully integrated into biotechnology programs, such as by partnering with local companies to design a curriculum relevant to local biotechnology jobs. For example, the Santa Fe Community College biotechnology program focuses on algae to specifically prepare graduates for roles in local algal biomass and chemical production companies, like Apogee Spirulina and Eldorado Biofuels (Santa Fe Community College n.d.). Other community colleges have industry advisory boards (IABs) of local industry and academic representatives that meet regularly to improve the training and curriculum of the program. Solano Community College's (SCC's) biotechnology program is an illustration of how industry-academic coordination with an IAB can lead to innovative educational training (Solano Community College n.d.). For over 20 years, SCC has partnered with local biotechnology companies to develop an educational training program where students learn not only the conceptual underpinnings of laboratory techniques, but also the transferable technical skills required to maintain regulatory records and run state-of-the-art equipment. **To train students with the necessary hands-on skills they need to succeed in the growing bioeconomy, the NSF should facilitate creation of a center for four-year institutions focused on improving access to and engagement in extensive experiential learning opportunities.**

II. Recommendation

We recommend that NSF create a center, named Bioeconomy Workforce Readiness for Undergraduates Center (BWRUC), focused on providing access to extensive experiential learning opportunities for undergraduates at four-year institutions. Such a center would serve a similar function to NSF's existing InnovATE*BIO* network or its recently announced Experiential Learning for Emerging and Novel Technologies (ExLENT) program, but would focus on bridging the experiential learning gap of students at 4-year institutions in biotechnology and biomanufacturing (NSF n.d.). The center could be supported through the Directorate for Technology, Innovation, and Partnerships (TIP) and could be developed in collaboration with Manufacturing Innovation Institutes such as BioMADE, BioFABUSA, and NIIMBL, which can leverage existing academic and industry networks to support collaboration between these sectors. This center would create a community of academic colleges and universities and serve as an avenue to support the development and dissemination of scalable models for classroom and internship-based experiential learning.

i. Project-based learning

The BWRUC should support projects to develop scalable experiential learning opportunities for undergraduates. Specifically, the center should <u>prioritize the funding of curriculum development for project-based learning (PBL) labs that meet industry needs</u>, which could be in the form of grants to revamp existing methods-based labs. Industry should be involved in the curriculum design and implementation process, including serving in an advisory capacity for research projects, and curriculum development should be coupled with assessments that measure impact on student skills development and job outcomes. PBL labs are known by other names and variations, such as "inquiry-based", "research-based", "discovery-based" labs or Course-based Undergraduate Research Experience (CURE), but the general intent is the same across all of them. With PBL and similar labs, the traditional methods-based, "cookbook" laboratory course is transformed into a project- or research-based lab where students learn laboratory techniques through a long-term project. While most instructional learning labs teach students common molecular biology techniques, they are often taught as one-off, standalone lessons that do not connect from week to week. One week may focus on running a PCR reaction and analyzing it on an agarose gel and the next week may be a protein gel with protein samples, with neither the DNA nor protein samples related to each other. On the other hand, PBL labs feature a continuous, course-long project with a goal in which students use multiple techniques in a sequence to answer a hypothesis or solve a problem, such as cloning a mutant gene and expressing it in *E. coli* to purify and study. PBL labs are thus a more effective form of teaching laboratory methods compared to traditional methods-based laboratory courses (Fukami et al. 2012; Movahedzadeh et al. 2012; Berchiolli, Movahedzadeh and Cherif 2018; Li et al. 2019). In addition, PBL labs ensure that all students are receiving experiential learning training within the academic environment, thus promoting equity by removing obstacles tied to students' capacities or access to external activities such as internships. The most significant barriers to implementing a PBL lab is the time to develop course materials and scaling to larger class sizes (Spell et al. 2014). Nonetheless, instructors at universities across the nation have successfully implemented such programs at scales up to ten 30-student labs and created frameworks with easily adaptable course material to reduce the barriers to adaptation (Regassa et al. 2007; Gormally et al. 2011; Treacy et al. 2011; Baskhi, Patrick and Wischusen 2016; Mordacq et al. 2017; Shuster et al. 2019).

PBL labs should ideally establish and foster collaboration between curriculum developers and industry partners. By coordinating with industry, curriculum developers can design courses that engage students in real-world problems, leading to a high-impact learning experience. The "Engineering Clinic" program at Rowan University is a model example: this program requires students in all of their engineering departments, including biomedical engineering, to take a 4-year series of courses dedicated to research, project design, and laboratory experiments (Rowan University n.d.). In the first two years, students complete semester-long projects through courses that teach basic engineering design principles and laboratory skills. In the second two years, students complete an independent project in an academic lab that can be sponsored by an industry partner. Students are expected to treat this course as a professional role while learning both technical and soft skills, such as how to work collaboratively in teams. Assessing the efficacy of this and similar models, like CUREs at Northwestern and Louisiana State University, and developing approaches to scale for other undergraduate institutions should be a core focus of the center so that students develop key skills that prepare them for their future careers (Bakshi, Patrick, and Wischusen 2016; Mordacq et al. 2017).

ii. Internships

In addition, the center should provide <u>coordination and financial support for paid industry internships</u>, including co-op programs. Industry internships provide students with direct experience working in a start-up or corporate environment and play an important role in developing the skills and connections required for job placements. Moreover, it's vital to emphasize that many students, especially those from underserved backgrounds, often miss out on these enriching experiences due to financial constraints. Addressing this financial barrier is essential to level the playing field and ensure that all aspiring students have equitable access to these career-launching opportunities. Institutes of higher education are incentivized to develop internship programs: in a survey of college freshmen, students indicated that they are more eager to attend universities that land their graduates good jobs (Stolzenberg et al. 2020). Industry benefits from the expansion of internships programs by being able to access a larger pool of workers with relevant skill sets.

The BWRUC should develop internship models, evaluate their impact on job placements, and create resources to support the implementation of effective models across institutes of higher education. At individual colleges or universities, models could include integrating co-op programs – where students work as paid employees or affiliates, full-time for a company for a number of months – into undergraduate degree plans. For example, Northwestern University offers an optional co-op program, which placed nearly 30% of participants across engineering disciplines in biotechnology internships during the 2018-2019 school year (Northwestern McCormick School of Engineering 2019). The BWRUC should also consider piloting a centralized internship program in which the center itself coordinates student placements at a set of participating companies. Such a program could be particularly useful for smaller companies that might otherwise lack the resources to host interns. EBRC coordinates a similar internship program for PhD students that has historically seen engagement from smaller companies and startups (EBRC n.d.). Programs like this one should be developed for undergraduates in engineering biology. These programs would primarily connect with life science and adjacent departments rather than with university career centers for more targeted outreach. Finally, the BWRUC should offer mechanisms to fund internships to reduce barriers to participation for underrepresented groups. NSF has already developed funded, non-academic internship programs for PhD students. The BWRUC should consider offering a similar program, or even require that all internships in association with the center be paid, to achieve equity goals.

By supporting the development of internship programs, the center will be able to assess the efficacy of internship programs for undergraduate training, determine mechanisms to incentivize student participation, and develop resources and programs that enable universities to more readily offer internship opportunities to their students.

III. Implementation

Creating change in academic systems can take time. At its inception, InnovATE*BIO* had the advantage of leveraging an existing network of institutions built over 20 years. To accelerate its impact, the BWRUC should start by building on established networks of organizations offering four-year degree programs. These networks include the Engineering Biology Research Consortium and biomanufacturing-focused Manufacturing Innovation Institutes. Each of these organizations also has extensive industry participation that can be leveraged to ensure that programs developed via the center are aligned with industry needs. Measurements of skills development, student participation in internships and undergraduate research experiences, and job placements post-graduation are some ways to assess the impact of programs developed via the center. Impact can also be measured by the number of institutions participating in the center and the extent to which these institutions implement experiential learning programs, such as PBL labs or internship placement programs.

Government has a vested interest in maximizing equitable benefit from biotechnology; education and training pathways that facilitate entry into the job market could enable engineering biology to more efficiently advance sustainability and equity goals (EBRC 2022). In 5 years and with $8 million in funding, InnovATE*BIO* institutions have created programs that have placed students at over 750 employers in 1400 locations across the United States. With similar investments, the BWRUC can help advance undergraduate education to improve job readiness and advance the bioeconomy. **As federal agencies implement plans to support education and training, initiatives that foster academia-industry coordination and expand access to experiential learning should be key priorities to secure the future promised by engineering biology.**

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