2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #50384

Experiential Learning for Biotechnology Workforce Development-Preliminary Outcomes from an NSF ExLENT Program

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Experiential Learning for Biotechnology Workforce Development: Preliminary Outcomes from an NSF ExLENT Program (Work-in-Progress)

Abstract

Background: Biotechnology is a rapidly expanding industry that requires inclusive, skills-based workforce development pathways to prepare diverse learners for roles in biomanufacturing. The Experiential Learning for Emerging and Novel Technologies (ExLENT) Biomanufacturing and Bioprocessing Certificate Program, an NSF-funded, partnership-based initiative led by Utah State University, was designed to address regional workforce needs in the U.S., Intermountain West. Grounded in Kolb's Experiential Learning Theory, the program integrates online modules, hands-on laboratory training, project-based learning, mentoring, and micro-internships to support learners' success

Purpose: The purpose of this study is to examine early implementation outcomes of the ExLENT Biomanufacturing and Bioprocessing Certificate Program, focusing on changes in learner's technical competencies, professional skills, and STEM identity after participating in the six-week experiential training.

Method: The program consists of four stackable certificate tracks including: Upstream Processing, Downstream Processing, Biomanufacturing, and Quality Assurance/Quality Control (QA/QC). Recruitment prioritizes students from two-year institutions and groups historically underrepresented in STEM. The pre- and post-program self-assessment surveys were administered to the first cohort (N = 12) to measure perceived gains in technical knowledge, professional competencies, and identity as STEM learners.

Conclusion: Findings show notable increases in self-reported technical skills across all certificate domains, with particularly strong gains in bioreactor operation, cell-based assays, and QA/QC practices. Participants also reported improvement in communication, teamwork, critical thinking, and time management. Lessons learned and program refinements are discussed to inform future cohorts and contribute to scalable models for biotechnology workforce development.

Keywords: *experiential learning, biotechnology, biomanufacturing, workforce development, credentialing. micro-internships, experiential Learning Theory*

Introduction

Biotechnology is a rapidly evolving industry with the potential to transform sectors ranging from healthcare and agriculture to environmental sustainability and advanced manufacturing. As the United States accelerates its investment in the bioeconomy, the demand for a skilled, diverse, and inclusive biotechnology workforce has become increasingly urgent. National directives such as Executive Order 14081 and the Congressional Research Service Report R46881 on the U.S. Bioeconomy innovation emphasize the critical need for expanded technician-level training, clear career pathways, and inclusive workforce development strategies that engage historically underrepresented populations in STEM [1], [2]. To address identified regional training deficiencies and meet this national imperative, this NSF-funded Experiential Learning for Emerging and Novel Technologies (ExLENT) project "NSF EXLENT Biomanufacturing and Bioprocessing Certificate Program" establishes a regional biotechnology training and education partnership that leverages experiential learning to equip individuals with the technical and professional competencies needed for success in the biotechnology industry. In this paper, we present the rationale, curriculum framework, and preliminary findings of our project implemented at Utah State University (USU).

Background

The United States biotechnology sector is a cornerstone of the emerging bioeconomy, contributing over $210 billion to GDP and creating more than 640,000 jobs nationwide [3]. However, the workforce development in biotechnology has not kept pace with industry growth. For instance, reports from the National Academies and federal and the White House OSTP agencies highlight persistent gaps in technician-level training, limited biomanufacturing expertise, and insufficient pathways for underrepresented groups in STEM careers [4], [5]. Executive Order 14081 explicitly calls for expanded education and training programs to strengthen the biotechnology workforce and promote equity across regions and demographics [1].

Despite this national call for workforce in the biotechnology sector, the U.S. Intermountain West region faces significant challenges in preparing its workforce in this career field. For instance, a recent survey conducted by this project team, with over 50 community colleges across eight states (i.e., Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming), found that most biotechnology programs are rooted in traditional biology curricula and lack critical components in biomanufacturing and bioprocessing, which are necessary for industry roles. Furthermore, enrollment in science and engineering associate degree programs in these states lags behind the national average, and industry-oriented short-format training programs are virtually nonexistent [6].

In this regard, experiential learning [7] offers a proven strategy to bridge these gaps. Grounded in "learning by doing," experiential approaches, such as project-based learning, internships, and mentoring, equip learners with technical and professional competencies while fostering STEM identity and career readiness. Recent systematic reviews affirm that experiential learning enhances problem-solving, teamwork, and adaptability, making it essential for preparing students for rapidly evolving technology sectors [8] .

To address these national and regional needs, we launched this initiative as a scalable, inclusive workforce development model. ExLENT integrates online instruction, hands-on laboratory training, and micro-internships with industry partners, leveraging Kolb's Experiential Learning Theory [7] to translate conceptual knowledge into applied skills. Strategic partnerships with biotechnology companies ensure authentic workplace experience and stackable credentials aligned with hiring needs.

Methods

Research Design

This study is part of a broader mixed-methods evaluation of an NSF EXLENT Biomanufacturing and Bioprocessing Certificate Program examining impacts on participants' technical knowledge, professional competencies, and STEM identity development. This paper reports preliminary findings from pre- and post-program self-assessment surveys administered to the first program cohort via Qualtrics. Surveys captured baseline skills and post-program changes in participants' self-perceived proficiency and learning outcomes. Self-assessment surveys are widely used in workforce development research to assess perceived learning gains in technical and professional domains [9], [10].

Program Structure and Participants

The program was delivered as an intensive six-week certificate training comprising four weeks of online instruction (synchronous and asynchronous) followed by two weeks of onsite experiential learning. The curriculum consisted of four stackable certificates—Upstream Processing, Downstream Processing, Biomanufacturing, and Quality Assurance/Quality Control (QA/QC), designed to reflect interdisciplinary competencies required for entry-level and early-career biomanufacturing roles. Certificates were vertically aligned from foundational science to applied process understanding and regulatory awareness, while horizontally integrated to promote system level thinking across biomanufacturing functions.

Program design was guided by Kolb's Experiential Learning Theory [7]. The instructional leadership for the program was provided by a program manager with over eight years of professional experience in biomanufacturing industry, supported by faculty from the department of Biological Engineering at USU. This background informed both the curriculum design and instructional approach, particularly in aligning course content with entry-level workforce expectations. Faculty and industry partitioners jointly facilitated the online modules and onsite laboratory instruction, ensuring coherence between theory and applied practice. Online modules introduced core concepts including cell culture and fermentation, purification strategies, manufacturing workflows, and current Good Manufacturing Practices (cGMP). Content selection and sequencing for both the online and on-site components were informed by consultations with regional biotechnology industry partners, who identified common skills gaps among early-career hires. The two-week onsite phase, conducted at USU Synthetic Biomanufacturing Institute and partner industry facilities, incorporated project-based learning [11], [12] and micro-internships [13]. For example, participants conducted iterative bioreactor experiments examining inoculum density effects on microbial growth. Faculty and industry mentors supported participants throughout the onsite phase, and micro-internships at partner companies provided exposure to authentic workplace environments.

Recruitment for Cohort 1 focused on the U.S. Intermountain West region to address regional workforce needs and broaden access to biomanufacturing training. Outreach strategies included a dedicated program website, distribution of digital and print flyers to regional community colleges and technical programs, and direct, in-person recruitment visits to partner institutions. These approaches were intentionally selected to reach students at two-year colleges and individuals from groups historically underrepresented in STEM who may have limited exposure to biomanufacturing career pathways. Twelve participants completed the program, representing both community colleges and universities across the region.

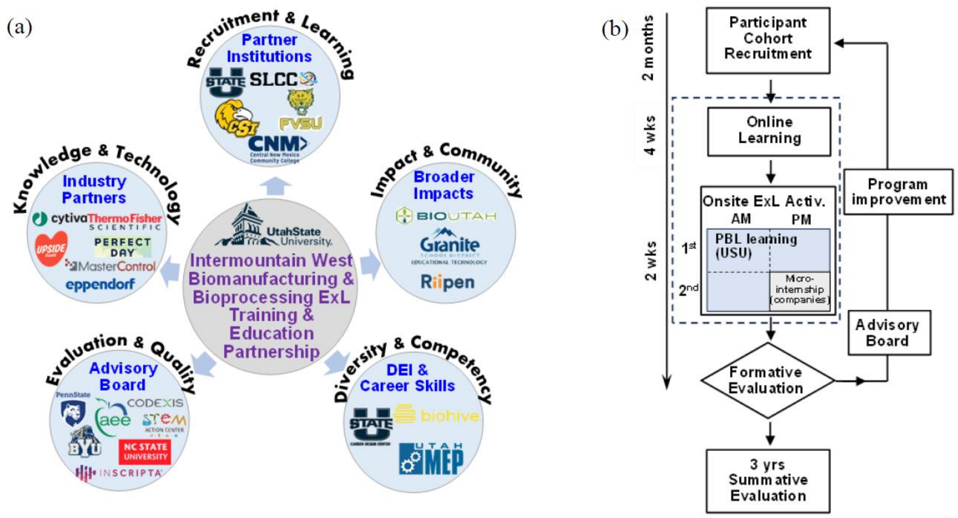

Figure 1. (a) Partnership-enabled EXL program model with five pillars. (b) Experiential learning workflow illustrating six-week program structure

Data Collection and Assessment

Data collection included pre-program surveys to establish baseline technical and professional skills and post-program surveys to measure changes in self-reported proficiency and confidence. Surveys used a five-point Likert scale and open-ended questions [14], [15] to assess pre/post changes in participants' confidence, knowledge, technical awareness of biomanufacturing, and specific career and professional skills. Other assessment methods to be reported in future papers. Additional assessments included instructor observation of laboratory tasks such as bioreactor sampling, Chinese Hamster Ovary (CHO) cell thawing and passaging, and adherence to safety protocols. Online engagement was monitored through discussion responses and interactive sessions, and participants completed a final poster presentation evaluated for technical communication and data interpretation. Technical skills assessed corresponded to all four certificate tracks mentioned above, while professional skills included communication, teamwork, critical thinking, time management, and problem-solving. While the comprehensive program evaluation included other assessment modalities, such as direct instructor observation of hands-on skills (e.g., bioreactor sampling and CHO cell passaging) and an integrative final poster presentation, the results reported in this preliminary study are derived exclusively from the comparative analysis of the pre- and post-program self-assessment survey data.

Results

Participant Demographics

As shown in Figure 2, there were twelve participants (N=12) in the first cohort who remained consistent across the program. Even though all the participants completed the program, only nine (9) of them completed the pre-survey, and eight (8) completed the post-survey. Most participants were between 18–24 years old (77.8%), with a smaller proportion aged 25–34 (22.2%). Gender distribution included 55.6% of women and 44.4% of men. Racial and ethnic representation was predominantly White/Caucasian (70%), with additional representation of Hispanic/Latino/a/x (20%) and Black/African American (10%) populations. Most participants resided in suburban areas (55.6%), followed by urban (33.3%) and rural (11.1%) regions.

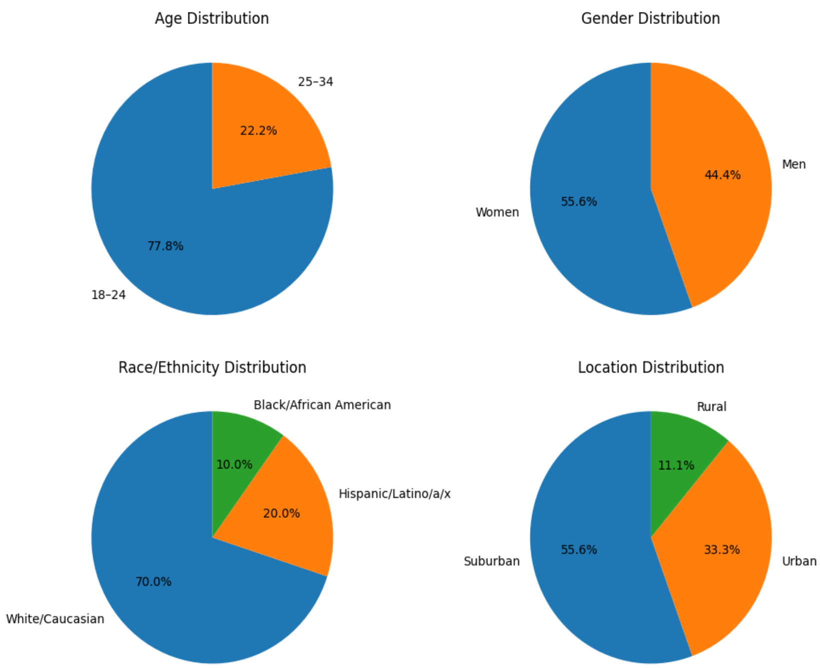

Figure 2. Participant demographics by age, gender, race/ethnicity, and participants' location.

Education and Employment

At baseline, most participants (67%) had completed some college or an associate's degree; participants had previously earned a bachelor's degree, and another had earned a graduate degree. Employment status varied, with four participants employed part-time, two full-time, and three being unemployed.

Table 1. Pre-survey respondents by Employment and Education Status

Employment Status (pre-survey)	**#s of participants (pre-survey)**	**Education Status**	**#s of participants (pre-survey)**

Employed full-time (35+ hours per week)	2	Only a high school diploma	1
Employed part-time (< 35 hours per week)	4	Some college or an associate's degree	6
Unemployed	3	Bachelor’s degree and a Graduate or professional degree	2

Technical Skill Development

Figure 3 shows the changes in participants’ self-reported technical skill average ratings before and after training across the four domains of upstream processing, downstream processing, quality assurance/quality control (QA/QC), and biomanufacturing. The average for the pre-training ratings was relatively low, ranging from approximately 1.4 to 1.6 and indicating minimal to moderate confidence in these areas. The post-training ratings showed substantial improvement, increasing from 3.25 to 4.0 across all domains. The largest improvement among participants was observed in the upstream processing and biomanufacturing, improving from approximately 1.5 to 4.00, followed closely by downstream processing and QA/QC. These results suggest that the training program enhanced participants perceived technical competencies in core biomanufacturing processes.

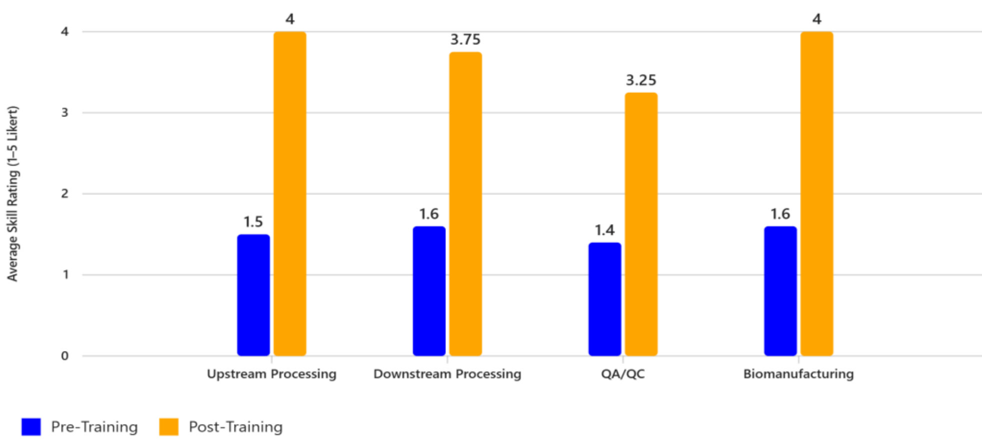

Figure 3. Technical Skill Development for pre- and post-training

Professional Skills

Figure 4 shows changes in participants’ self-reported professional skill ratings, before and after training, across communication, critical thinking, teamwork, and time management. While the pre-training ratings were relatively high, ranging from an average rating of 3.5 to 4.0, indicating moderate to strong confidence in these skills before the program, the post-training ratings demonstrated incremental improvement, increasing to approximately 4.0–4.5 across all domains.

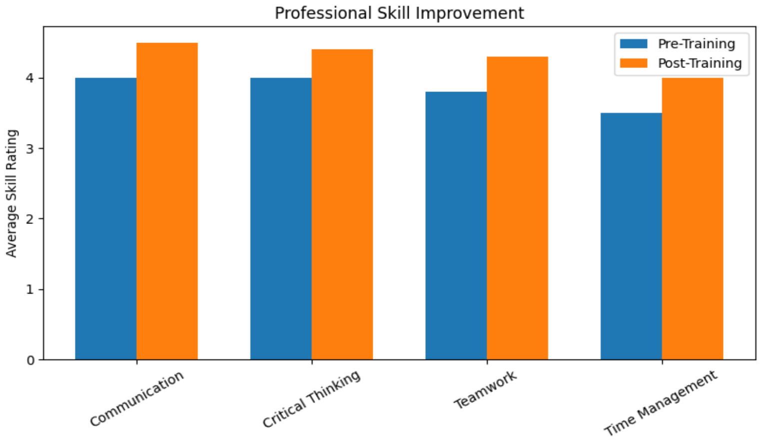

Figure 4. Comparison of pre- and post-training professional skill ratings

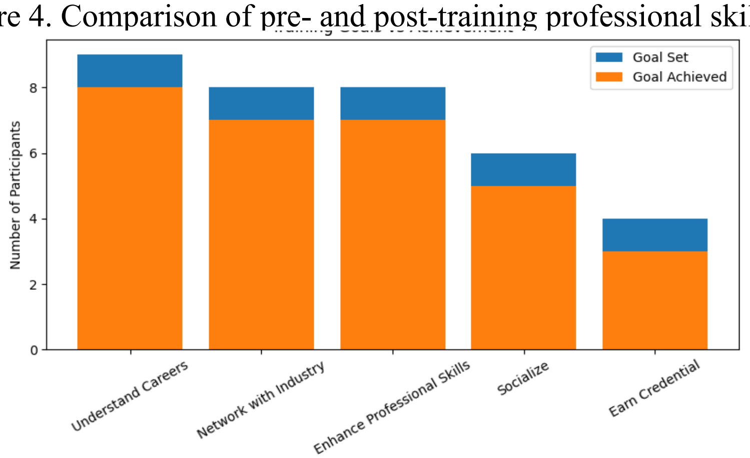

Figure 5. Training Goals vs. Achievement

The greatest gain, from approximately 3.5 to 4, was observed in time management, followed by teamwork and communication. These findings suggest that while participants entered the program with strong professional skills, the training further enhanced their confidence, particularly in managing time effectively

Training Goals and Achievement

Figure 5 compares participants who stated training goals with their reported achievements. The most frequently set goal was to understand careers (9 participants), followed closely by networking with industry and enhancing professional skills (8 participants each). Achievement rates were high across all categories, with 8 participants reporting success in understanding careers and 7 achieving networking and skill enhancement goals. Socializing was set as a goal by 6 participants and achieved by 5, while earning a credential was the least common goal (4 participants) and achieved by 3. However, all the participants who completed the four technical core domains received certificates. These findings indicate strong alignment between participants' expectations and outcomes, particularly in career awareness and professional networking.

Barriers to Participation
Pre-program survey responses identified financial constraints and travel logistics as the most significant barriers to participation. However, the post-program feedback suggested that these barriers were mitigated through program-provided stipends and virtual engagement options, reducing their impact on overall participation.

Positive feedback
Qualitative feedback from participants highlighted both positive experiences and areas for improvement, organized into key themes. For instance, the instruction quality was frequently praised, participants highlighting the effectiveness of teaching. "*Matthew did an amazing job in teaching,"* and *"Valued knowledge from instructors and speakers."*

Overall program satisfaction was also strong, with three respondents describing the experience as *"fantastic"* and noting its impact on their skills, education, and career. *"Helped me in all my skills, education, career, and overall quality of life."*

Applied learning and industry exposure were valued by two participants who appreciated real-world biomanufacturing tours and career development activities: *"Tours with ThermoFisher and Disgenix; career path paperwork; one-on-one talks with professors."* One participant emphasized the supportive cohort environment: *"Everyone was very supportive… a nice environment to learn and have fun."*

Suggestion for improvement
Suggestions for improvement centered on instructional design and logistics. Four participants requested extended hands-on lab sessions and more complex techniques: *"Needs to be more hands-on and not so much standing and watching."* Two participants recommended enhancing online engagement through required participation and quizzes: *"Turn cameras on in lecture"* and *"Small quizzes or required participation for online portion."* Additional logistical concerns included laundry service, early dorm access, and recreational facilities: *"Laundry service; early/extended dorm access"* and *"Lack of access to Aggie Recreational Center."* Other suggestions addressed scheduling (*"Finished early some days; more lab or classroom time would help"*) and residential environment (*"Some students were loud at night"*).

Table 2. Themed content for participant feedback

Theme (concise)	**Participants (n)**	**Feedback Examples**
Instruction quality	3	"Matthew did an amazing job in teaching." · "Matthew was a very good instructor." · "Valued knowledge from instructors and speakers."
Overall program satisfaction/impact	3	"Fantastic learning experience." · "Helped me in all my skills, education, career, and overall quality of life."
Hands-on lab time & complexity (need)	4	"More complex in-person techniques should be explored." · "Needs to be more hands-on." · "Hands-on portion could be longer."

Online engagement & participation (need)	2	"Turn cameras on in lecture." · "Small quizzes or required participation for online portion."
Applied learning & industry exposure	2	"Seeing real-life biomanufacturing." · "Tours with ThermoFisher and Disgenix; career path paperwork; 1:1 talks with professors."
Logistics & facilities (need)	2	"Laundry service; early/extended dorm access." · "Lack of access to Aggie Recreational Center."
Scheduling & evening activities (need)	1	"Finished early some days; more lab or classroom time would help."
Residential environment (need)	1	"Some students were loud at night."
Supportive cohort environment	1	"Everyone was very supportive… nice environment to learn and have fun."

Discussion

As a first-round implementation, these findings establish a baseline for understanding the potential of short-term, workforce-focused certificate programs in biomanufacturing. The findings from this program demonstrate meaningful benefits in both technical and professional competencies among participants, as well as strong alignment between training goals and outcomes. The demographic profile of the cohort, primarily young adults (18–24 years), with a majority identifying as White/Caucasian and residing in suburban areas, reflects the typical composition of early-career learners in STEM pathways. While the sample size was small, the diversity in race/ethnicity and gender representation suggests the program reached a varied audience, which is critical for equity-focused workforce initiatives.

Skill Development and Program Impact

The most notable improvement occurred in technical skill domains, where participants' confidence increased from minimal/moderate levels pre-training to high levels post-training. Participants reported significant improvement in downstream processing and QA/QC, indicating that hands-on laboratory experiences and exposure to biomanufacturing processes were effective in building applied competencies. These findings align with prior research emphasizing experiential learning as a cornerstone of technical skill acquisition in STEM workforce programs [16], [17], [18]. For instance, the study by Kline and colleagues [16] studied a postsecondary construction management program that used a hybrid format for course delivery. They found that technical skills and soft skills improved across course domains when they integrated hands-on laboratory exercises.

Professional skills, such as communication, teamwork, and critical thinking, were rated relatively high at baseline, yet still showed incremental improvement after training. This suggests that while participants entered the program with strong foundational soft skills, structured activities and collaborative learning environments further enhanced these competencies. The improvement in time management is especially noteworthy, as it reflects participants' ability to adapt to the program's schedule and balance multiple tasks, skills that are highly valued in industry settings.

Goal Achievement and Participant Satisfaction

Participants reported high achievement rates for their stated goals, particularly in understanding career pathways and networking with industry professionals. In addition, the program established sustained relationships with 16 regional biotechnology companies, forming the foundation of an ongoing network for experiential learning, internship exploration, and future curriculum alignment. While formal post-program employment outcomes were not tracked for this initial cohort, these partnerships are intended to support continued engagement between participants and industry beyond the program. The fact that all participants completing the technical core domains earned a credential further reinforces the program's alignment with industry-recognized standards and its potential to enhance employability. The certificates represent verified exposure to industry-identified biomanufacturing competencies. The immediate signaling value of the certificates to participants suggests a need for clearer communication regarding how such credentials function within early-career hiring contexts.

Barriers and Recommendations

Although financial and travel barriers were identified before the program, these challenges were largely mitigated through stipends and virtual engagement options. However, qualitative feedback revealed areas for improvement in program logistics and instructional design. Participants expressed a strong desire for extended hands-on lab sessions, more complex in-person techniques, and greater interactivity during online components. Suggestions such as requiring cameras during virtual sessions and incorporating quizzes to maintain engagement reflect participants' preference for active learning strategies.

Logistical recommendations, including laundry services, early dorm access, and recreational facilities, highlight the importance of addressing non-academic factors that influence learner experience and retention. These insights are consistent with literature on holistic program design, which emphasizes the role of supportive environments in fostering persistence and satisfaction [19], [20].

Implications for Workforce Development

The positive outcomes observed in the ExLENT cohort 1 program suggest that short-term, intensive training models can effectively enhance technical and professional skills while supporting career exploration and networking. Future programs should consider integrating additional hands-on components, refining online engagement strategies, and addressing logistical concerns to optimize learner experience. Also, it is better for future programs to incorporate explicit guidance on integrating certificates into resumes and professional profiles, along with structured mechanisms for collecting employer feedback on the perceived value of the credentials in hiring and onboarding decisions

. Moreover, expanding recruitment to include a broader demographic range could strengthen the program's impact on diversity and inclusion in the biotechnology workforce.

Acknowledgements

This work is supported by the National Science Foundation (NSF) Grant # 2347213. This work reflects the views of the authors and not necessarily those of NSF.

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