ASSESSMENT

Long-Term Outcomes of Biotechnology Student Participation in Undergraduate Research Experiences at Delaware Technical Community College

Virginia Balke, Linda Grusenmeyer, John McDowell,
Delaware Technical Community College

Abstract

Engagement in undergraduate research experiences (UREs) has a positive impact on student skill development, scientific identity, and retention in STEM. Incorporating UREs into two-year programs would greatly benefit the diverse, nontraditional student populations enrolled at community colleges. This article describes the infusion of the bioscience/biotechnology program at Delaware Technical Community College with course-based and mentored research experiences, which may serve as a model for other institutions. Studies done with the Office of Institutional Research revealed a concurrent increase in enrollment and graduation rates. Retrospective interviews with graduates from the program highlight the critical influence of research, the mentor-student relationship, a sense of community, the development of transferable skills and self-efficacy, and subsequent successes in pursuing higher education and employment.

Keywords: *biotechnology education, community college alumni, community college graduation rates, course-based undergraduate research, mentoring, student outcomes*

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Undergraduate research experiences (UREs) have a positive impact on STEM students, particularly female, underrepresented minority (URM), and first-generation students (Espinosa 2011; Gentile, Brenner, and Stephens 2017; Haeger and Fresquez 2016; Hurtado et al. 2009; Jones, Barlow, and Villarejo 2010). Increasing numbers of community colleges have adopted both classroom-based and mentored models of undergraduate research experiences (Hensel and Cedja 2014; Hewlett 2018). This movement holds promise for greater access to STEM fields through wider student participation (Bangera and Brownell 2014) given that almost half of all URM students in the US are enrolled in community colleges (American Association of Community Colleges 2020), and more than half of all students receiving STEM bachelor's degrees complete some part of their education at community colleges (NCSES 2010). With lower costs, open-access policies, and support for nontraditional students, community colleges serve populations who benefit greatly from exposure to these opportunities (Olson and Labov 2012).

Many publications on UREs report on perceived gains in skills, confidence, and career plans gathered from student surveys and interviews (Lopatto 2010; McIntee et al. 2018; Mraz-Craig et al. 2018), whereas others use institutional data to investigate student retention and graduation rates (Rodenbusch et al. 2016). Several studies delve deeper into nuanced dynamics, such as whether mentoring relationships influence retention, how scaffolding across multiple courses affects skill development, and how multi-semester research experiences influence development and identity as a scientist (Adedokun et al. 2014; Linn et al. 2015; Nagda et al. 1998; Thiry et al. 2012). Because UREs are relatively new to community colleges, there are few studies that examine their impacts on community college students or ask alumni to take a retrospective look at the impact of UREs on their career trajectories or pursuit of advanced degrees (Nerio et al. 2019). This article examines the long-term education and career outcomes for alumni who participated in a URE-infused program over a five-year period in the Bioscience/Biotechnology Program at Delaware Technical

TABLE 1. BIS-BIT Program Biology and Chemistry Courses

Year 1	
Fall	Spring
Biology I Chemical Principles I	Biology II *Principles of Microbiology* Chemical Principles II
Year 2	
Fall	Spring
Biotechnology I Organic Chemistry I Analytical Chemistry I	*Biotechnology II* Organic Chemistry II Analytical Chemistry II

Note: Italicized courses have embedded undergraduate research experiences.

Community College (DTCC). Working with data from the National Student Clearinghouse and the college's Office of Institutional Research, the authors have shown that infusion of the program with multiple opportunities for UREs corresponded with increased program enrollment, higher graduation rates, and continuation of higher education. Interviews with graduates provided more detailed insights into the program's influence on student success after graduation, whether students continued their education or entered the workforce.

The Research-Infused Program

DTCC is an open-access college serving a diverse population of approximately 15,000 students. It is both a technical and a community college with three campuses across the state, each addressing the needs of local industry and preparing students to enter directly into the workforce upon graduation or to transfer to a four-year institution. The Biotechnology/Bioscience (BIS-BIT) Program described in this article, which is housed in the Department of Biology and Chemistry on DTCC's Stanton campus, has an average enrollment of 200 students and graduates about 12 students per year. The program is rigorous, requiring students to take five biology courses and six chemistry courses (see Table 1); all science courses include a laboratory section. Lack of college readiness, financial issues, and family obligations extend the time to degree completion from two years to an average of four years. Responding to current industry needs, the college has created articulation agreements with local four-year institutions to which most students transfer upon graduation.

Course-Based Undergraduate Research Experiences

To provide research experiences for the maximum number of students, laboratory activities were modified to provide scaffolded experiences that emphasized scientific and transferable skills through a sequence of three biology courses (see Table 1). The laboratories consisted of instructor-designed research-based projects in which students took ownership of the project, had opportunities for reiteration to complete the project, and were vested in the outcome. Scientific literacy was explicitly emphasized through laboratory reports in which students were expected to use scientific terminology and style when analyzing data and communicating results. New in-class activities were introduced to strengthen critical thinking, reinforce group work, and encourage development of a deeper understanding of the primary literature and the ethical conduct of research.

Mentored Undergraduate Research Experiences

Students also had the opportunity to work on a research project in a traditional mentored model. Many of the research projects were related to course-embedded projects, building on several of the same technical skills, thus lowering the threshold to entry. Each semester, including summers, up to 12 students worked with two to four faculty members on a variety of long-term projects. Because faculty recruited students from their courses and any interested students were encouraged regardless of where they were in the course sequence or of their grade point average, demographics of mentored students reflected those of the program and the college (see Table 2). The length of student participation in mentored research ranged from one semester to three years. Participating students developed their research skills through multiple semesters, with an initial focus on techniques and reading scientific literature, followed later by troubleshooting and data analysis. Eventually students were able to postulate hypotheses and design their own experiments. Since multiple students were working on the same projects, there was an opportunity for peer mentoring, with more experienced students aiding newer ones.

Several of the research projects were developed in partnership with research faculty at the University of Delaware and Delaware State University, contextualizing students' contributions to the larger scientific community. As these relationships grew, the reputation of the DTCC students improved, leading to more opportunities for summer internships and transfers.

Students working on mentored research received grant-funded stipends, easing some of the financial burdens that frequently required them to work outside of the college. As the program evolved, credit-bearing research courses were created to provide compensation for faculty mentors, with each mentor receiving the registration fees for his or her section.

Biannually, students presented their research at a campus research poster session, which helped garner support for the undergraduate research program and expand it to other departments. Grant funds also supported student travel for presentations at regional and national conferences, for

TABLE 2. Academic Metrics and Demographics of DTCC's Stanton Campus and Program Students (2008–2014)

	Campus-wide	CUREs only	CUREs plus mentored research
Graduation rate	N/A	34.5% (41/119)	46.8% (22/47)
Average time to completion of AAS (years)	3.25	5.3	3.9
Average GPA	3.03	3.25	3.4
Percentage of female participants	57%	55.2%	56%
Percentage of URM participants	32.5%	38.6%	42.7%

Note: DTCC = Delaware Technical Community College; CUREs = course-based undergraduate research experiences; AAS = associate of applied science degree; URM = underrepresented minority. Time range includes the students who participated in mentored research in 2008 before CURE implementation.

TABLE 3. Summary of Study Questions, Data Sources, and Analysis

Study question	Data source	Analysis
To what extent have the DTCC BIS-BIT program's rates of enrollment and completion changed since implementation of research opportunities?	Enrollment and completion data for five years prior to and following research infusion	Comparison of descriptive data
How do graduates fare in employment and further education following participation in the URE-infused BIS-BIT program?	Interviews with a random sample of graduates regarding current employment and education status	Descriptive data regarding career and education attainment for sample of alumni
How do graduates of the URE-infused BIS-BIT program describe the program's influences, supports, and/or deficits in their own subsequent education and employment?	Interviews with a random sample of graduates regarding reflections and evaluation of undergraduate research opportunities at DTCC	Identification of important program features in view of students' graduation, further education, and employment

example, the biannual research symposium of the Community College Undergraduate Research Initiative, the National Conference on Undergraduate Research (2013, 2017), and the Council on Undergraduate Research–sponsored Posters on the Hill in Washington, DC.

Impact Studies

The research presented uses institutional and interview data to gain a broad picture of the impacts of the URE-infused program and to identify aspects that alumni found most beneficial to furthering their education and STEM careers (see Table 3). Recognizing that instructional practices and research experiences may only partially influence student outcomes, methods were intentionally combined to gather different types of information. First, existing institutional data were compared for changes in enrollment and graduation rates between two five-year periods, pre- and post-implementation of UREs. In the second phase, long-term student outcomes of URE participation were examined by interviewing a random sample of alumni, encouraging them to reflect on their research experiences and assess their impact in light of their current education or employment.

Institutional Data Analysis

Annually 200 students enrolled in the BIS-BIT program, with fewer than 20 completing their degrees. Because high numbers of students struggled with developmental courses or first-year biology and chemistry and dropped out or transferred before the research-infused courses, program growth and graduation rates were calculated using only students who had declared a BIS-BIT major and passed Biology I and Chemical Principles I. This was the student population prepared to enroll in Principles of Microbiology, the first biology course with embedded research.

Comparing the 2004–2009 (prior to URE infusion) students with the 2009–2014 (post-URE infusion) group, there was a meaningful increase in both program enrollment and graduation rates (see Table 4), without a similar increase in campus-wide enrollment or number of graduates (DTCC 2020; see Table 5). Comparison also was performed between populations participating in course-related undergraduate research experiences (CUREs) alone and those with both CUREs and mentored research, finding meaningful but not significant differences in GPA, graduation rate, and time to completion between the two (see Table 2). The

TABLE 4. BIS-BIT Program Metrics before and after Infusion of Undergraduate Research Experiences (UREs)

	Enrollment	Graduation rate
2004–2009 (pre-URE)	74	24.3% (18)
2009–2014 (post-URE)	148	36.5% (54)

Note: BIS-BIT major students who passed first-semester chemistry and biology courses ($*\chi^2$, $p < 0.05$, $df = 1$)

TABLE 5. DTCC's Stanton Campus Metrics for 2008–2009 and 2013–2014 Academic Years

	Fall enrollment	Number of graduates
2008–2009	3,857	544
2013–2014	3,572	330

National Student Clearinghouse (2015) tracked all DTCC students who had participated in mentored research from 2009–2014, regardless of major. Of 90 students, 26 (29 percent) were continuing their education at DTCC and 47 (52 percent) had transferred to a four-year institution.

Interviews

Sampling Strategy

From the pool of BIS-BIT graduates from 2012–2016, 25 were randomly selected and invited to participate in interviews. Twelve graduates agreed to be interviewed for this study. Demographically, the sampled group was similar to all BIS-BIT graduates and differed slightly from DTCC's Stanton graduates at that time (see Table 6).

Instrumentation

A semi-structured interview protocol, adapted from the Accreditation Board of Engineering Education (ABET) student survey instrument (Volkwein et al. 2004), guided collection of new data. Although the DTCC BIS-BIT program is not accredited by ABET, the survey's focus on the impact of learning authentic problem solving in context aligns well with the goals of the DTCC BIS-BIT program and its focus on UREs.

Interview questions were reviewed and selected by program faculty to align with program goals and practices, as well as with research on typical components and outcomes of URE. To estimate timing and ensure that items were clear, relevant, and well-ordered, the protocol was piloted with a recent graduate who was not part of the sample. Interviews lasted approximately 30 minutes and were held either face-to-face or by phone. The second author, who had no previous experience with the program or alumni, administered and initially coded all interview data.

An introductory statement encouraged interviewees to think back to a specific time, and Likert-type questions served to focus memory and standardize some statements of evaluation. The interview was conversational in nature, and alumni were encouraged to elaborate on their ratings and describe their experiences. In addition, open-ended questions were designed to elicit additional context and depth. All interviewees gave a verbal or written statement of informed consent, and none asked to skip or omit any part. Interviews were recorded and transcribed.

A coding scheme was jointly developed and refined by the authors to capture statements regarding important features and benefits identified in earlier studies of URE. Transcripts were first read as a whole and coded by one researcher. If any additional impacts or insights were noted at this phase, they were coded. As the process continued, patterns and relationships developed within the data. The authors met again to clarify new understandings, insights, and themes, including multidimensional learning, real-world applications, the value of learning in a community, and perceived benefits and obstacles to further education and career (see Table 7). Most frequently, interviewees mentioned the benefits of interpersonal relationships with peers, faculty, and members of the greater scientific community, particularly in gaining information critical to their research projects and career pathways. The respondents did not discuss learning specific skills but rather recognized their increased confidence and understanding of the scientific process and the importance of their work to society.

Alumni Outcomes

STEM Degrees and Careers

Interviewees provided information regarding current education—that is, whether they were currently working (or if they ever had worked) toward a four-year degree, the degree major, full- vs. part-time status, and anticipated graduation date. All also were asked about current full- or part-time employment, job title, and typical responsibilities. Following graduation from DTCC, most students continued with STEM education and/or employment in STEM-related fields.

Of the nine students then currently enrolled in bachelor's programs ($n = 6$) or pursuing advanced degrees ($n = 3$), all anticipated finishing their degree programs within two years and continuing to work in research labs or professional placements or moving into graduate training. All nine were employed either full time ($n = 1$) or part time ($n = 8$) in STEM fields ($n = 5$) or non-STEM jobs, including IT, retail, restaurants, and child care. The three who were not enrolled in school at that time were working full time, two in bioscience careers and one in computer sciences. One of the three had completed a BS in biology. The other two indicated that they might consider earning a four-year degree in the future.

TABLE 6. Demographics of DTCC's Stanton Campus Graduates, BIS-BIT Graduates, and Interview Participants, 2012–2016

	Campus-wide	All BIS-BIT	Interview sample
Percentage of female participants	55.4%	49%	42%
Percentage of URM participants	36.9%	49%	58%
Percentage of mentored research participants	N/A	50.9%	67%
Average age	25	27	26.25
Average GPA	3.06	3.23	3.25

Note: DTCC = Delaware Technical Community College; URM = underrepresented minority

TABLE 7. Key Analytic Themes, Subordinate Codes, and Number of Coded Instances

	Instances (*n*)
UREs are multidimensional learning experiences	
Learn/apply lab skills	11
Master course content; incorporate writing, math skills	7
Learn professionalism and teamwork	17
UREs yield positive outcomes	
Confidence	22
Career advice, including transfer advice	20
Job readiness, including new technologies	11
Open doors to new opportunities	10
UREs address real-world problems	
Useful, important scientific or social implications	24
Science is iterative, collaborative, and open to inquiry (scientific process)	10
Benefits of UREs occur within a community (benefits attributed to—)	
Peers: unspecified	7
Faculty	17
Peers: project or research team	47
Other professionals: off-campus REUs or professional experiences	21
Concerns when deciding to further education	
Information gap	5
Funding, including credit transfers	5
Time commitment, including credit transfers	10
Question level of preparedness	2

Note: UREs = undergraduate research experiences; REU = Research Experiences for Undergraduates program, National Science Foundation

Program Impact

Alumni highly valued their research experiences in the BIS-BIT program, describing a multidimensional learning environment focused on researching real-world problems and situated in relationships with generous, caring faculty and smart and supportive peers.

Recalling their research projects, graduates communicated a sense of participating in scientifically relevant projects with broad implications, for instance, "bats with white-nose disease," "testing soil bacteria from a farm to see the impact of fertilizers and pesticides on soil microbes," and "what proportion of ticks in New Castle County had

markers for Lyme disease." One compared this work to lab activities at another college where "they were very simple. At Del Tech we were like real scientists. We were doing important work."

Faculty members were characterized as warm, open, caring, and motivating. Students remembered instructors sharing their own research during lectures, advising students on career paths, and preparing them for "real world work-place." They held high standards for student professionalism and competence but offered support for reaching these goals.

Alumni recognized that written and oral communication and sharp math skills were vital to long-term success. Some offered insights into the scientific process. All recognized the power of learning new concepts in a problem-focused setting that required critical thinking, deep understanding of text and lecture material, and technical skill:

> Every lab was new. You couldn't rely on the same techniques. You were constantly learning. And what the book says does not always appear that way in the lab. You have to think and see differences.

Long-term research experiences fostered confidence, enabled growth, and opened doors to more challenges, as two alumni commented:

> We had to understand lab processes and equipment to get correct results and to know when they aren't [correct]. It was a year-long process and if we made mistakes we had to start over. It taught us patience and to be careful, and to have pride because MY name was on it. It reinforced classroom learning, which was the best part for me. (emphasis in original)

> Improved leadership skills come from the long term [ongoing research projects.] You take over from someone and then pass the project on to someone else.

In course-based research experiences, all students worked in formal, assigned peer groups, whose members were shuffled during the semester. As one alumnus commented, "It was really annoying at first." Teams, however, provided students with additional opportunities for teaching and learning from each other. Faculty members held an expectation that together students could work out some of their own solutions. One respondent noted, "We were expected to work as a team. We had to work and plan for ourselves, solve problems ourselves." Looking back, alumni recognized their classmates were "sharp," and "smart people from diverse backgrounds, but equally important" who they "could depend on."

Even if a student had not participated in mentored research projects, they benefited indirectly through peer relationships. A network of informal peer mentoring grew. Upper-level students who helped with lab techniques and equipment problems also shared information about educational opportunities and credit transfer agreements to the area's four-year institutions and graduate programs. For some, this was a primary source for transfer advice.

Overwhelmingly, alumni realized they were confident and well-prepared for the next career challenge. Several recalled a point when they understood their own high level of preparedness relative to others, whether working on lab assignments at their new higher education institution or employed in industry, government research facilities, or university research laboratories. A few wondered if more DTCC BIS-BIT students realized how well trained they were they also would consider graduate degrees. As one respondent commented,"Biotech students here are ready for it, if they knew how [to access graduate programs]."

Discussion

This study has a few potential limitations. There was an attempt to address generalizability by providing both qualitative and quantitative data, but program numbers were small, as was the pool of alumni from which the interviewees were drawn. It was hoped that the unaffiliated interviewer might overcome the reluctance of some to participate regardless of further employment or education, and it was encouraging to note that the interviewees' demographic and academic performances were similar to those of the pool of recent graduates. However, questions remain about how the experiences of nonrespondents might differ. Finally, this study does not investigate the experiences of those who did not complete the program. Understanding the experiences and concerns of program alumni offers a foundation for future research to examine this important question.

The BIS-BIT program at DTCC provided students with multiple opportunities for undergraduate research, both in courses and through mentored research. Analysis of institutional data reveals a corresponding increase in the number of students who continued after their first-semester core courses as well as a significant increase in graduation rates. Although the data do not prove a direct correlation, retrospective comments by alumni indicate the importance of the mentor-student relationship, skill development over multiple semesters, and opportunities for teamwork to their growth as scientists and increased self-confidence. This echoes findings from studies at other institutions (Adedokun et al. 2014; Linn et al. 2015; Nagda et al. 1998; Nerio et al. 2019; Thiry et al. 2012). Of note, the graduates' discussions focused on the transferable skills they gained, considering this more important to their success than the course content itself.

Taken together, these reflections offer insight into how program components may have worked together to support their success. Although they detailed many features and benefits of UREs identified in this study's preliminary research, they also highlighted the importance of other factors potentially overlooked for their simplicity, specifically, the precious commodities of time and money when pursuing higher education today, the central organizing role of relationships, and the power of competence and confidence to sustain those in transition.

This interview group represented all the diversities of nontraditional community college students. Five of the twelve were older than 21 years when they first entered. Six attended at least one other college before DTCC. Half were first-generation college attendees. Five were from immigrant families. Four needed more than four years to complete their AAS degree. It is recognized that none of these factors limit a student to attending community colleges, and the study did not directly address the decision to enroll in community college. Nevertheless, respondents revealed its importance in their statements of concern about graduation and decisions to continue on education or career paths. It was in evidence when they recalled earlier academic struggles, inability to enroll elsewhere, and aimlessness. It was reflected in the high premiums they placed on time; money; proximity to home; and, for some, the flexibility to drop in and out by semester as needed. The journeys of these alumni could have been undertaken only at a community college such as DTCC.

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Virginia Balke
Delaware Technical Community College,
emerita, vlbalke@gmail.com

Virginia Balke taught biology courses for 20 years at DTCC and is now retired. She developed CUREs and mentored research students in a variety of molecular biology, microbiology, and ecology projects. She served as principal investigator for a National Science Foundation (NSF) Advanced Technological Education grant and a coprincipal investigator on the Community College Undergraduate Research Initiative. Balke played leading roles for statewide National Institutes of Health–IDeA Network of Biomedical Research Excellence (INBRE) and NSF Established Program to Stimulate Competitive Research (EPSCOR) grants, working to further institutionalize undergraduate research at the college.

Linda Grusenmeyer served as program manager for DTCC's INBRE and EPSCOR grant projects. She earned her MEd from the University of New Orleans and an EdD in educational leadership with a focus on science curriculum from the University of Delaware. Grusenmeyer has served as project director for several multiyear, multisite evaluations of federally funded research projects. She is interested in pedagogical, institutional, and social supports that broaden access to STEM.

John McDowell is a faculty member in the Department of Biology and Chemistry at the Stanton campus of DTCC. He earned his BS in agriculture from University of Delaware and a PhD in microbiology and immunology from Virginia Commonwealth University. McDowell emphasizes science education using high-impact practices to train future members of the bioscience workforce. This includes course-embedded research in laboratory courses and mentoring undergraduate students in research projects outside of program courses.