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## A Cross-Disciplinary Doctoral Emphasis in Bioentrepreneurship: A Case Study of the University of California Davis Biotechnology Program



Denneal Jamison-McClung\* and Judith A. Kjelstrom

*UC Davis Biotechnology Program, University of California, Davis, CA, USA*

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**Abstract:** The Designated Emphasis in Biotechnology (DEB) graduate program is the largest cross-disciplinary doctoral program at UC Davis, encompassing 29 disciplines and training over 200 students in bioentrepreneurship annually. Core coursework includes foundational training in biotechnology and team science, a bioentrepreneurship seminar series, training in bioethics and an industry internship. Personalized mentoring and professional development activities that emphasize leadership, science communication and entrepreneurship have been keys to the growth and success of the DEB, including the recruitment and retention of ~20% students from underrepresented backgrounds. Institutional support has allowed DEB program directors to build and sustain this unique model program through extramural training grant awards and the cultivation of public-private partnerships. A case study of the DEB is presented to encourage the development of similar cross-disciplinary doctoral programs in bioentrepreneurship.

**Keywords:** Bioentrepreneurship, designated emphasis in biotechnology program, cross-disciplinary doctoral program, bioethics, public-private partnerships, extramural training grant awards.

### 1. INTRODUCTION

The Designated Emphasis in Biotechnology (DEB) was established in 1997, as a foundational graduate degree program aligned with the goals of the NIH-NIGMS Training Grant in Biotechnology [1, 2] and aimed at expanding the entrepreneurial skills sets of doctoral students interested in applied research and careers in industry. Now approaching its twentieth anniversary, the DEB is a well-established, cross-disciplinary doctoral degree program focused on bioentrepreneurship, having grown from an inaugural student cohort of 11 to a steady-state of approximately 220-230 students. Over the past few years, there has been increased national attention on the need for doctoral programs to provide students with transferrable professional skills relevant to career paths in both the public and private sectors, particularly in the biomedical sciences [3-5]. Many Master's degree programs in bioentrepreneurship exist, both nationally and internationally, but there are noticeably fewer doctoral training programs with a focus on the "business of science" [6-9]. Indeed, newly enrolled DEB students often report that a deciding factor in their decision to pursue graduate studies at UC Davis is the existence of the DEB program and opportunity to acquire bioentrepreneurial skill sets during the doctoral degree program. To encourage the establishment of similar cross-disciplinary bioentrepreneurship programs at large research-intensive universities, the DEB is presented as a programmatic case study.

### 2. UC DAVIS BEST PRACTICES FOR ESTABLISHING CROSS-DISCIPLINARY GRADUATE PROGRAMS

There is a long-standing tradition of cross-disciplinary graduate student training at UC Davis and the DEB is currently the largest program of this type on campus. Two formal structures for administering cross-disciplinary graduate programs exist within the Office of Graduate Studies, graduates groups and designated emphases (DE's). Over half of the 99 graduate programs at UC Davis are organized as interdisciplinary graduate groups <https://gradstudies.ucdavis.edu/programs/graduate-groups>. Graduate groups allow faculty with common research interests, but housed in different departments, to collaborate on the development and administration of graduate degree programs (MS and PhD). Because graduate groups are not administered by a single department, oversight and staff support occurs at the college level under the auspices of a lead dean, rather than a department chair. Graduate group program chairs are periodically elected from participating faculty and related administrative work may rotate to the chair's academic unit or will be handled by assigned staff in the lead dean's office.

Beyond graduate groups, designated emphases (DE's) permit an additional layer of complexity in tailoring graduate student instruction to areas of academic interest. The formal process to establish a DE program was developed in 1988, when the need for specialized interdisciplinary graduate coursework important for more than one doctoral program, particularly in response to emerging technologies, was recognized. To establish a DE, two or more departmental or

\*Address correspondence to this author at the UC Davis Biotechnology Program, University of California, Davis, CA, USA; Tel: 530-752-5090; Fax: 530-752-4125; E-mail: dsjamison@ucdavis.edu

**Table 1. DEB-Affiliated Doctoral Programs.**

Graduate Group or Departmental Program Lead Dean	Field of Study	DEB-Affiliated Doctoral Programs
College of Agriculture and Environmental Sciences (CAES)	Agricultural and Environmental Sciences	Agricultural and Environmental Chemistry; Animal Biology; Entomology*; Food Science; Horticulture and Agronomy; Nutritional Biology; Pharmacology and Toxicology; Plant Pathology; Soils and Biogeochemistry
College of Biological Sciences (CBS)	Biological and Life Sciences	Biochemistry, Molecular, Cellular and Developmental Biology (BMCDB); Integrative Genetics and Genomics; Neuroscience; Plant Biology
College of Engineering (COE)	Engineering	Applied Science Engineering*; Biological Systems Engineering*; Biomedical Engineering; Chemical Engineering*; Civil and Environmental Engineering*; Computer Science*; Electrical and Computer Engineering*; Materials Science and Engineering*
College of Letters and Sciences - Division of Mathematics and Physical Sciences (CLS-MPS)	Physical Sciences and Mathematics	Biophysics; Biostatistics; Chemistry; Statistics
School of Medicine	Medicine	Microbiology; Molecular, Cellular and Integrative Physiology (MCIP)
School of Veterinary Medicine (VetMed)	Veterinary Medicine	Immunology; Integrative Pathobiology

\*Departmentally-based doctoral program

graduate group doctoral programs work together to develop a comprehensive proposal, including a compelling rationale describing the DE's academic value and mission, lists of affiliated faculty members and doctoral programs, curricular and degree requirements, organizational structure and bylaws, and letters of support from affiliated graduate program administrators (chairs, deans). New DE proposals are submitted to the Office of Graduate Studies and reviewed by the Academic Senate Graduate Council. Given the administrative work needed to prepare and review proposals, establishment of DE graduate programs typically takes a year or more. Completion of DE degree requirements are recognized on the doctoral student's diploma (e.g. "Ph.D. in Genetics with a Designated Emphasis in Biotechnology"). As with graduate groups and departmentally based doctoral programs, DE's are subject to periodic program reviews by Graduate Council, ensuring a high quality educational experience for doctoral students in the program [10].

A third approach to adding topical expertise to an existing graduate program at UC Davis is the Graduate Academic Certificate (GAC). GAC's are "a structured sequence of courses and requirements that focus on a specialty or area of expertise not offered by a regular graduate degree program". GACs have less intensive coursework requirements and are noted on participating student's transcripts as a certificate, unlike the official degree notation that reflects the rigor of a DE program. Though less comprehensive, adopting a GAC model may be useful for institutions in the early stages of developing a bioentrepreneurship doctoral degree program [9, 11].

A challenging aspect of both graduate groups and designated emphasis degree programs, including the DEB, is the need for regular cross-institutional resource negotiations to provide staff and financial support for student recruitment and admissions activities, administration of program courses, student advising and tracking progress toward degree, and completion of periodic program reviews by the Office of Graduate Studies. There are currently 21 DE graduate

programs offered at UC Davis, including the DEB, which is affiliated with 29 departmental and graduate group doctoral programs (Table 1) across four academic colleges and two professional schools.

### 3. DEB ORGANIZATIONAL STRUCTURE AND COURSEWORK

#### 3.1. Student Recruitment and Enrollment

Biotechnology Program directors are often invited by affiliated graduate groups and programs to give short presentations on the DEB during spring recruitment and most affiliates include information on the DEB in the information packets provided to prospective PhD students. In addition, the Office of Graduate Studies hosts online resources for prospective students that highlight the connection between DE's and affiliated doctoral programs.

Enrollment of new DEB students typically occurs during the first year of the doctoral degree program and many students contact the DEB program prior to arrival on campus. Occasionally, students join the DEB during the second year of study. Because a significant portion of required coursework must be completed before the qualifying exam, however, second year enrollment is less common. The enrollment process requires that a student submit an application form to the Office of Graduate Studies verifying that they understand the DEB degree requirements. The DE application form must be signed by the student's graduate program advisor, as well as the faculty chair of the DE [12].

First year doctoral students applying to join the DEB generally have not selected a major professor. Once selected, it is important for DEB students to confer with major professors regarding DEB degree requirements and expectations, particularly the 3-6 month biotechnology internship for which students will eventually travel off-site (domestic and international locations). Most faculty in DEB-affiliated doctoral programs are familiar with the DEB and

many have joined the program as advising faculty. Faculty join the DEB program at various stages; some faculty join when newly hired, others join when selected by a DEB student as a major professor. In either case, the process for adding a new faculty member to the DEB is relatively straightforward; the faculty member must read the DEB program bylaws and agree to uphold said bylaws in writing (via email is acceptable). Currently, the DEB program has 269 faculty members.

### 3.2. Coursework and Degree Logistics

Students enrolled in the DEB are expected to complete a core course, seminar series, bioethics course and three-to-six month internship in order to fulfill degree requirements (Table 2). Though additional coursework is required, the average time to degree for DEB graduates has held steady at a reasonable ~5.5 years, which is in the average range for life science and engineering PhD graduates. DEB students are generally keen to pursue an industry internship and most do so toward the end of their doctoral careers (years ~4-5). When DEB graduates are asked which elements of DEB required coursework were most professionally valuable, the majority indicate that the “real world” internship was invaluable.

The Biotechnology Fundamentals and Applications course (DEB263 – 2 units) blends life science and engineering principles with an overarching theme of bioentrepreneurship. This course must be taken prior to the students’ qualifying exams and a DEB faculty member must be a member of the qualifying exam committee in order to evaluate the students’ knowledge of biotechnology. Each winter quarter, DEB263 has ~40-60 enrolled students who are assigned to interdisciplinary teams of scientists and engineers. Teams are tasked with developing an original biotechnology business plan and elevator pitch utilizing their unique blend of disciplinary expertise. Given the heterogeneous composition of the core course (drawing students from 29 disciplines), team projects span an array of topics (*e.g.* biodefense agents, biofuels, cancer diagnostics and therapeutics, industrial products, personal genomics apps, *etc.*). Peer-to-peer exchange to foster innovative, entrepreneurial thinking is promoted throughout the course. In its most recent iteration, a social media assignment was added to help students hone science communication skills for various audiences and investigate current norms in biotechnology business discussions and product marketing [13].

### 3.3. DEB Program of Study

Though drawn from 29 doctoral disciplines, most DEB students follow a similar five-year course of study. Program directors have developed a chart outlining a typical DEB program of study to assist incoming DEB students with integration of DEB requirements with their graduate group or departmental doctoral program course requirements (Table 3).

## 4. DEB PROFESSIONAL DEVELOPMENT ACTIVITIES

Incoming doctoral students are acutely aware of national conversations around the need for a diversified approach to graduate education [3, 4, 14, 15] and they are attracted to the program because of its emphasis on bioentrepreneurship, including the introduction to regulatory paradigms, intellectual property, the trials and tribulations of raising capital for start-up ventures and the importance of clearly communicating research ideas to a variety of audiences that are received via required coursework. Complementing the framework of required courses, program directors implement a variety of annual group activities and individualized training opportunities that focus on developing skills in entrepreneurial leadership, project management, science communication and engaging policy makers.

Doctoral students are also increasingly aware of opportunities to launch or join start-up biotechnology companies directly after graduate school [16, 17]. For example, during the first quarter of the MCB294/ECH294 Current Progress in Biotechnology seminar series, DEB students are introduced to the Venture Catalyst START™ program which offers a suite of business tools and services for budding campus entrepreneurs interested in forming companies (<http://research.ucdavis.edu/offices/vc/start/>) DEB alumnus, Dr. Zane Starkewolfe, heads up the START™ program and helps DEB bioentrepreneurs in accessing available resources, including LegalNet incorporation services, MentorNet business mentoring, SBIR grant writing workshops, assistance in finding incubator space, *etc.* The DEB program also has a close working relationship with the Graduate School of Management, home of the Big Bang Business Plan Competition [2]. DEB student bioentrepreneurs have been among the winners of the Big Bang for the past four years.

**Table 2. DEB Required Coursework.**

DEB Course Number	DEB Course Title	Total Units
DEB 263	Biotechnology Fundamentals and Applications Lecture Course	2
GGG296 (or approved bioethics course substitute)	Scientific Professionalism and Integrity Seminar	1
MCB294/ECH294	Current Progress in Biotechnology Seminar (1 unit seminar for 3 quarters, may substitute MIC292 for one quarter)	3
MIC292 (elective seminar)	Seminar in Bacterial Physiology and Genetics (industry guest speakers from Novozymes)	1
MCB282	Biotechnology Internship (3 - 6 months)	~7-12 variable units per quarter

Note: DEB required courses are in the process of transitioning to new "DEB" course numbers (~2015-2018).

**Table 3. DEB Program of Study.**

Year 1	Make an appointment with Dr. Judy Kjelstrom, DEB program coordinator, to discuss DEB program admission.
	Submit a complete DEB application form signed by the Graduate Student Advisor and DEB Faculty Chair to the Office of Graduate Studies.
	Begin required coursework (must take DEB263, MCB/ECH294 seminar series and an approved ethics course prior to the Qualifying Exam).
	Apply for relevant DEB-related fellowships and traineeships.
Years 2-3	Finish required coursework and prepare to take the Qualifying Exam (QE). Ensure at least one DEB faculty member is included on the QE committee.
	Start building science communication skills and polishing a professional curriculum vitae (CV):
	Present a Pizza Chalk Talk.
	Develop a professional CV with guidance of program administrators (DEB template).
	Present a poster at the Annual Biotech Retreat.
	Enroll in at least three quarters of MCB/ECH294 Current Progress in Biotechnology seminar series. Volunteer to go to lunch with an industry speaker.
	Volunteer for 1-2 outreach events or activities per year. Each quarter, opportunities are sent to the DEB student listserv (high school student e-mentoring, high school seminars/elevator-pitch, Picnic Day, regional career fairs, Teen Biotech Challenge web design competition, <i>etc.</i> ).
Apply for relevant DEB-related fellowships and traineeships.	
Year 4	Establish internship professional goals and meet with program administrators to begin looking for opportunities at least one year prior to the ideal internship start date. Timing varies between students - the internship may be completed post-QE thru graduation. Student must enroll in MCB282 to receive credit hours for degree completion.
	Finalize the professional CV and template cover letter with help of program administrators.
	Audit MCB/ECH294 Current Progress in Biotechnology seminars and accompany industry speakers to lunch for professional networking and development of internship leads.
	Continue building science communication skills, volunteering for outreach and updating the professional CV.
	Begin writing the doctoral dissertation and publish scholarly works.
Year 5	Conduct a 3-6 month internship at a biotechnology company, research institute or national laboratory.
	Finish writing the dissertation and give an exit seminar.

Note: The table above represents an example of a typical DEB academic training plan. Actual patterns of degree progress may vary between students.

Prowess in science communication via multiple media platforms is essential for today's bioentrepreneurs [13]. The DEB program provides guidance and many opportunities for students to learn how to pitch research ideas quickly, concisely, and at the appropriate technical level for the listening audience, as well as how to tell a compelling story. At the rigorous end of the science communication spectrum, monthly Pizza Chalk Talks provide an informal venue for DEB students to present a high level technical overview to an interdisciplinary audience of peers. At the opposite end of the communication spectrum, ~50 DEB students per year participate in informal science education to the public (*e.g.* Powerhouse Science Center NSF-funded POP Net Science Communication Fellows Program, UC Davis Picnic Day) and K-14 outreach (*e-mentoring*, seminars, hands-on demos, *etc.*).

In terms of written communication for diverse audiences, the DEB program recently piloted a policy brief writing workshop and added training in science communication via social media to the core course (DEB263). In addition, DEB students are leading a social media outreach project, "Science Says", which communicates science-based information on biotechnology topics *via* social media

platforms, including blogs, Twitter (@SciSays) and YouTube (<https://davissciencepolicy.wordpress.com/>). The purpose of Science Says is to engage the general public in myth-busting common biotechnology misconceptions, particularly in the agricultural biotechnology sector.

## 5. DEB PROGRAM GRADUATES CAREER TRAJECTORIES

Having built an agile educational ecosystem to develop transferrable bioentrepreneurship and leadership skills in DEB doctoral students, the Biotechnology Program directors recognize that STEM career paths will continue to wind through a shifting landscape of research priorities and innovations. To help predict where STEM career paths will widen, narrow, emerge and disappear, it is useful to identify trends in the career trajectories of recent DEB graduates. However, tracking graduate student careers post-degree can be challenging. To address this challenge, the Biotechnology Program has an active presence on social media platforms, such as LinkedIn, Facebook and Twitter, in order to stay connected with recent graduates and build a sense of community that transcends student cohorts. Currently, we have career trajectory data for ~93% of DEB graduates (196

known/218 total DEB graduates. Over the past twenty years, DEB graduates have pursued a wide range of STEM careers, with approximately half of graduates entering the public sector and half entering the private sector. We contend that training in bioentrepreneurship is crucial for STEM doctoral students pursuing careers in academia, as well as the biotech industry, given the increasing importance of public-private partnerships for academic research.

## 6. INSTITUTIONAL SUPPORT FOR PROGRAM LEADERSHIP

Institutional support for the dedicated effort of UC Davis Biotechnology Program faculty has been key for the success of the DEB graduate program. Biotechnology Program directors work with campus leadership across affiliated graduate programs, colleges and schools and cultivate professional networks to facilitate internships and bioentrepreneurial activities. Dense social networks, both on and off campus, are essential for linking DEB students with opportunities to explore non-academic career paths [2]. Since the 1990's, Biotechnology Program directors have leveraged professional networks to help place ~200 students in internships.

Biotechnology Program directors are deeply involved in proposal development and award administration for interdisciplinary federal training grants (e.g. NSF CREATE-IGERT [DGE 065984]; NIH-NIGMS Training Grant in Biomolecular Technology [T32-GM08799]). Student support in the form of federal fellowships and traineeships since the establishment of the DEB is in the range of several million dollars. Extramural support provided by training grant awards early in the establishment of the DEB program facilitated doctoral student recruitment and the piloting of professional development activities that have since been integrated as foundational components of the DEB (e.g. Annual Biotechnology Retreat for NIH fellow to showcase their research).

The DEB has excellent recruitment and retention of doctoral students from diverse backgrounds, including ~50% women (116 female students/230 total students) and ~20% underrepresented minority (URM) students (45 URM students/230 total students). The high level of DEB program diversity may be attributed, in part, to efforts of Biotechnology Program faculty directors, who openly engage in professional activities pertaining to diversity in STEM and strive to create a culture of inclusion among DEB participants. For example, the program directors actively serve as faculty co-advisors for the DEB student group, "Equity in STEM and Entrepreneurship" (ESTEME). Provision of personalized mentoring and strategic career guidance to all DEB students throughout their doctoral program of study is likely another factor contributing to DEB demographic diversity. Mentoring intensifies as students prepare to conduct the required three-to-six month internship and make the transition from "all but dissertation" (ABD) to doctoral graduates. Studies of graduate students from underrepresented backgrounds have shown that the establishment of strong mentoring relationships is a critical factor for retention and degree completion [18].

## CONCLUSION

The DEB program has been steadily growing since its inception in 1997, with approximately 230 current students and 218 graduates. Of DEB graduates, half have pursued careers in the private sector (industry and non-governmental organizations) and half have pursued careers in the public sector (e.g. academia and government). The DEB continues to attract large numbers of life science and engineering students interested in bioentrepreneurship and serves as a model doctoral program for cross-disciplinary education in this area. Several organizational and pedagogical components underpin the success of the DEB program and should be considered as essential elements by institutions interested in building programs similar to the DEB. First, institutional frameworks (e.g. transparent policies and practices) for the development of cross-disciplinary doctoral programs should be developed if they do not already exist. Second, one or more faculty program directors with expertise in graduate education and bioentrepreneurship should be identified and supported at a level consistent with a mid-career research faculty member at full time equivalent effort (1.0 FTE). With full attention to program development, directors can then pursue extramural funding and build the professional relationships essential in supporting bioentrepreneurship pedagogy. Finally, a pedagogical framework of required courses, seminars, experiential learning activities (e.g. internships, job shadows, etc.) and professional development opportunities should be crafted with the workforce needs of regional industry partners in mind.

## CONSENT FOR PUBLICATION

Not applicable.

## CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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