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Enhancing graduate education by fully integrating research and professional skill development within a diverse, inclusive and supportive academy

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Jacinda K. Dariotis, PhD, MAS, MA, MS, is the Professor in the Research Methods sub-unit of the School of Education and Director of the Evaluation Services Center (ESC) in the College of Education, Criminal Justice, and Human Services (CECH), and Director of the Institute for Interdisciplinary Data Science at the University of Cincinnati (UC). She received her doctorate and masters in Human Development and Family Studies and masters in Statistics from Penn State University and a masters concentrating in Developmental Psychology from Columbia University. After serving as faculty for nearly a decade in the department of Population, Family, and Reproductive Health at the Johns Hopkins School of Public Health (where she currently holds an adjunct faculty position), she joined UC and began directing the Evaluation Services Center in early 2015. As Director of Research in CECH from 2016-2019, Dr. Dariotis supported the research needs of faculty, student, and staff including consulting on proposals, identifying appropriate funding mechanisms, and organizing a research methods consulting service available during the academic year. In fall of 2017, she was appointed Director of the Institute for Interdisciplinary Data Science, a new institute committed to developing a culture and community of data analytic experts who collaborate on projects to address real-world issues.

Dr. Dariotis is a basic, applied, and transdisciplinary scholar who integrates methods and content from numerous disciplines. Her areas of specialization include research and evaluation methods, survey research, biosocial methodologies, prevention and translational science, public health, adolescent and young adult risk-taking decision-making and behaviors, stress reactivity, and mindfulness-based programs. She adopts a collaborative approach to research and evaluation projects; collectively, she and her colleagues have received funding from local, state, and federal agencies. She has authored or co-authored over 50 articles published in top-tired journals, over 100 scholarly presentations, and over 200 technical and evaluation reports. Dr. Dariotis is committed to quality research and evaluation to promote the health and well-being of individuals, families, and society as well as capacity building to equip and empower community and academic partners with meaningful and high quality data and sustainable tools to make informed decisions about current and future programming needs.

Prof. Mark Crocker, University Kentucky

Mark Crocker received BSc. and Ph.D. degrees in chemistry from the University of Bristol in the U.K., and spent two years as a NATO postdoctoral researcher at the University of Wisconsin-Madison. Thereafter he spent 15 years working in industry for first Shell Research and then Degussa's automotive catalyst division. In 2003 he moved to the University of Kentucky (UK) where he is currently a Professor in the Department of Chemistry and an Associate Director of the Center for Applied Energy Research. At UK he leads a research group focusing on biofuels and environmental catalysis.

Enhancing graduate education by integrating research and professional skill development within a diverse, inclusive and supportive academy

1. Background

1.1. Challenges faced by graduate education and training in engineering and the sciences

Graduate education and training often take a monodisciplinary approach that is not informed by best educational practices, ignores the needs and preferences of trainees, and overlooks the increasingly interdisciplinary and international nature of research [1], [2]. Traditionally, most graduate training tends to follow a model that lacks synergy and faces common challenges across disciplines, such as student mentoring relying on a single adviser [3] and the lack of training for both mentors and mentees [1], [4], [5], [6]. In addition, graduate training is also challenged by the fact that the skills students need are self-evident to advisors but rarely communicated to students, producing suboptimal results [7], [8]. Indeed, graduate programs tend to employ a one-size-fits-all approach that undervalues the diverse learning experiences and cultures of students [9]. Furthermore, there are issues associated with even the most effective tools for the training of STEM professionals, such as developmental network-based mentoring [9], [10] and career-transferable skill development [1]. For instance, mentoring has been proven to improve retention and performance [11], [12], [13], leadership [14], [15], [16], and student involvement in graduate school [17], [18], [19], [20], especially among underrepresented minority (URM) students [11], [16], [17], [19]. However, mentoring is typically challenged by the lack of adequate training *not only for mentors* [21] *but also for mentees*, an issue only recently emphasized by mentoring experts [1], [5], [6]. Similarly, although the skills that STEM graduate students need are well known, students are commonly left to drive their own development, with "sink or swim" constituting the default advising style [7], [8]. This is unfortunate, particularly since graduate education that is integrated with interdisciplinary research can help students become part of a trained and diverse workforce equipped to meet society's many challenges.

2. Enhancing graduate education and training in engineering and the sciences

2.1. Proposed traineeship model

Against this backdrop, a National Science Foundation Research Traineeship (NRT) program is being established at the University of Kentucky (UK) to enhance graduate education by integrating research and professional skill development within a diverse, inclusive and supportive academy. In this contribution, we describe the key features of this NRT, the main goal of which is to generate an innovative model for STEM graduate student training by identifying and implementing the most effective tools for the training of STEM professionals. In future contributions, we intend to showcase data from the NRT, focusing on the evaluation of its constituent parts.

Briefly, this multi-year academy includes two required courses (one focused on research-related content and another on transferrable skills) and two elective courses, which together constitute the basis of a graduate certification. Other features include two summer internships (one inter-departmental and one at an external institution), peer mentoring of subsequent trainee cohorts, and initiatives including collaborative research grant proposals and annual symposia respectively pursued by and co-organized with the trainees. Table 1 provides an overview of the program components and their timing.

Table 1. Overview of Traineeship Program Components and Timing

Traineeship Year	Traineeship Year 1			Traineeship Year 2			Traineeship Years 3-4
Semester	Fall	Spring	Summer	Fall	Spring	Summer	All
Required Courses and Internships	500 level course on research-related content	600 level seminar course on transferrable-skills	Internal trans-departmental internship/ student research project	Elective 500 or 600 level course #1	Elective 500 or 600 level course #2 (certificate)	External internship aligned with career path	Master's thesis or PhD dissertation research courses; Parker Dewey micro-internships
Required Shared Activities	Form student research teams	Prepare and submit collaborative research grant	Annual symposium; field trips to facilities	Peer mentor training (and service in research course)	Mentor junior students in research group/lab	Annual symposium; field trips to facilities	Annual symposia; field trips to facilities
Tailored Professional Development Activities	Professional development activities related to career interests; e.g., teaching experience and future faculty preparation for trainees interested in academic teaching careers			Professional development activities related to career interests; e.g., intellectual property and business training for trainees interested in entrepreneurial careers			Job hunting, resume, cover letter, interview coaching approaching graduation

The starting point of the academy will be a multi-departmental and interdisciplinary 3 credit hour 500 level course that is offered in the fall semester, focused on research-related content, and co-taught by the core faculty involved. This course will be composed of four one-month "units," each focused on a research question requiring extensive interdisciplinary collaboration to be answered. Teaching teams of at least three core faculty with the cumulative expertise needed to answer each question will co-teach each unit, emphasizing concepts that students must understand to address the research question at hand. During this course, which will be mandatory for trainees but also open for all STEM graduate students, several multi-departmental interdisciplinary student research project teams will be formed, each focusing on one of the research questions. Beyond the conclusion of this course, these student research project teams will participate in a number of initiatives designed to further integrate research and education and ensure interdisciplinarity. Examples include competitive collaborative research grants (for which each student team will be required to submit an interdisciplinary collaborative proposal), an annual research symposium (for which each student team will be charged with organizing a session) and trans-departmental internships. All of these will be implemented within the purview of a consortium connecting a number of centers, institutes and other units focused on areas related to the research in order to ensure topicality and the provision of adequate resources.

In addition to technical or "hard" skills, recent graduates need – but very often lack – "soft" or transferrable skills, including communication, leadership and teamwork [22]. Therefore, in the subsequent spring semester students will receive training on key transferrable skills in a 3 credit hour 600 level seminar course designed to integrate these skills with the research-related content covered in the foregoing 500 level course. This seminar course will train participants in communication, teaching, funding procurement, entrepreneurship, management, teamwork, conflict resolution, mentoring, leadership, and outreach as well as ethics and research-related skills. All NRT trainees will register for this seminar course, which will be co-taught by the core faculty and by guest speakers with expertise in different areas and which will be open to all STEM graduate students. Training will be offered for the development of each skill both during the seminar and beyond (through practical training in subsequent years); however, beyond the seminar course trainees will only be required to participate in a manageable number of activities most directly relevant to their individual development plan (*vide infra*).

Completing the interdisciplinary and seminar courses described above will give students 6 of the 12 credit hours needed to attain a topical certificate established through this NRT. Trainees will earn the other 6 credits by choosing from a curriculum including courses fulfilling both certificate and degree requirements so the anticipated time-to-degree is not extended. As they complete the course work required to earn the certificate and after they are certified, trainees will receive peer-mentoring training and serve as peer mentors to junior trainees and students in their groups and laboratories, a model which has proven valuable in graduate academic settings [23].

Trainees will be required to participate in a minimum of two summer internships, one in another department while working in their first summer with their student research team on projects stemming from the internal collaborative research grants and another internship working in a subsequent summer at the type of institution best aligned with their career interests [2], [24]. To this end, participating faculty will leverage their connections in academia, the private sector, government agencies, and national laboratories. Trainees will seek funding to participate in internships, particularly international ones to help them gain a global perspective [2]. Pre-internship trainee orientation will involve their mentors and graduate students with prior internship experience as peer-mentors, while internship hosts will receive training based on the on-line Mentor Development Program of the University of New Mexico [25]. Before the internship, expectations will be set and documented in conference calls involving trainees and their mentoring team – comprising graduate committee members, the peer-mentor and internship host(s) – which will inform evaluations used to gauge the progress and the success of the internship at its midpoint and conclusion. Annual field trips to facilities related to the research being performed will further expose trainees to relevant sites and careers. Close to graduation, trainees will receive coaching on job hunting as well as résumé, cover letter and interview preparation.

Moreover, this NRT will connect training elements with inter- and transdisciplinary research through a number of initiatives besides the interdisciplinary and seminar courses in which student research teams will be formed (*vide supra*). First, this NRT will launch an annual symposium including all elements of a scientific conference, i.e., a call for abstracts, keynote and plenary talks, and trainee-led oral and poster sessions. Participating in this symposium – and in its organization – will give trainees the opportunity to practice several of the skills described above in a way that is integrated with their research, while providing them with networking opportunities. The latter will be instrumental in a second initiative, namely, the internal collaborative research grants prepared during the 600 level seminar course, which will include all elements of a funding opportunity, i.e., a solicitation, competitive review, and a reporting process. Solicitation review criteria will include the extent of collaboration between trainees from different departments, the extent of inter- and transdisciplinarity and the broader impacts of the work proposed. In addition to helping students hone several of the aforementioned skills, this initiative will also help to ensure that the latter is not only interdisciplinary but also transdisciplinary in nature.

In short, this NRT will strive to redress the fact that most graduate research is monodisciplinary and takes place in a single laboratory or department, an inadequate approach both to train researchers and to solve complex problems. Therefore, fundamental questions have been identified and answers will be sought through inter- and transdisciplinary, integrative and convergent research, specific mechanisms – including trans-departmental internships, an annual symposium and internal collaborative research grants – being used to ensure that research is also integrated with education. Moreover, additional steps will be taken to train students to investigate the societal, cultural, behavioral, and economic consequences of their work, such as including both non-STEM researchers in graduate committees and non-STEM chapters in the theses and dissertations of trainees.

2.2. Recruitment, mentoring and retention of trainees with emphasis on broadening participation
The seminar course's skill development curriculum will be promoted during the recruitment and orientation of STEM graduate students, particularly focusing on URM students. While no arbitrary target has been set for the number of URM students to be recruited, this NRT will make every effort to maximize this number by leveraging multiple initiatives that will ensure that this NRT will broaden participation in STEM. Recruitment-wise, a) leveraging UK's Center for Graduate Diversity Initiatives and its nationally-recognized Minorities in Agriculture, Natural Resources and Related Sciences chapter; b) continuing to recruit students from HBCUs; and c) close collaboration with two NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (INCLUDES) projects, will broaden – both institutionally and geographically – the recruitment pool of talented and diverse students. Similarly, close collaboration with the U.S.-wide Louis Stokes Alliance for Minority Participation (LSAMP) will further broaden this recruitment pool to reach a national audience. Collaboration with these entities will transcend recruitment and provide trainees with ample opportunities to acquire, practice and refine the skills described in section 2.1, as trainees present their results and recruit in conferences, meetings and outreach events organized by these entities, and become members and/or join the leadership of them. In so doing, their professional and mentoring network will be expanded. Moreover, URM trainees will be surveyed periodically to probe their feelings of well-being, preparation, acceptance, belonging and distress, as well as their perception of how well-structured their departments and programs (MS/PhD/NRT) are. According to the topical work of Fisher et al. [26], these factors determine whether or not they perform (i.e., publish) at rates comparable to their male majority peers. Additional details regarding the evidence base for recruiting, mentoring, retention, and broadening participation strategies has been described in past contributions [27], [28].

The benefits of the academy (e.g., stipends, internships, field trips, etc.) will be advertised to students either before or after recruitment into the UK departments participating in this NRT to test the incentive effect [29]. Students, particularly URM students, will be encouraged to apply via a short form requesting basic background information and details related to their research interests, anticipated career path (academia, industry, government, etc.), and needs. Each of the trainees selected will be matched with a professor who will serve as a graduate advisor, graduate committee chair and formal mentor, as well as with two more professors in different departments – one STEM and one non-STEM – who will serve as committee members and co-mentors. Thus, recruitment, broadening participation, admission and advisory processes will be harmonized with those of all participating departments. Mentoring efforts will use as a starting point the motivation letter, which will be the first of many items and experiences informing the Individual Development Plan (IDP). This will be developed for each trainee using myIDP, the evidence-based model of the American Association for the Advancement of Science (AAAS) [30].

The IDP for each trainee will be tailored and personalized not only to accommodate their interests (as expressed in the application form) but also to expose them to a range of research-related career pathways (both within and outside academia), some of which they may not have considered. To this end, a Preparing Science Professionals Symposium – an event covering career paths ranging from scientific writing and communication to entrepreneurship, administration and policy – will be leveraged. This will give trainees an excellent overview that will further inform their AAAS IDP. In turn, this will help identify the professional development activities, beyond the transferable skill development seminar, that will be of greatest benefit to each trainee.

This living document will be added to a dynamic dossier used by trainees and their mentoring team to track progress, monitor the development of technical and professional skills, and keep their developmental network map (which trainees will receive the tools to produce and analyze [31], [32], [33]) updated and balanced. Subsequent additions will be made to sections corresponding to each skill targeted in the academy as trainees hone these skills throughout their studies. For instance, the mentoring team will add to the section on communication skills every time the trainee gives poster or oral presentations. This will provide each trainee a clear and personalized roadmap – including pitfalls to avoid and targets to pursue – to attain competency. Periodic dossier reviews (including during graduate committee meetings) will yield regular, structured feedback on proficiency and progress in each rubric. To standardize the vehicle through which competencies are assessed, feedback is given, and progress is measured, evaluation forms will be used by trainees and their mentoring teams both as a guide and as the means to make dossier additions.

3. Assessment

3.1. External evaluation design

This traineeship model will be externally evaluated to assess progress made toward NRT and program objectives. A cohort-sequential research design is used whereby three cohorts of trainees participate in the training program. The first cohort begins in project year 2 (2020-21 academic year). Existing data from previous cohorts of STEM graduate students will serve as retrospective cohort data for baseline comparisons. Data collected among STEM graduate students who participate in any NRT initiatives broadly open to other graduate students will be used for dosage comparisons (partial program exposure). Preliminary results will be shared during regular project team meetings to promote timely program improvement.

Qualitative data collection and analyses are particularly informative regarding project development and implementation (process/formative evaluation) to show what is occurring as well as to identify and explain successes, challenges, adaptations, and growth opportunities [34]. Formative evaluation activities will focus on project implementation, including the student recruitment and selection processes, curriculum development, and partnerships to promote sustainability. Quantitative data collection and analyses will be used for monitoring outreach (participants served) as well as a summative evaluation of outcomes (e.g., changes in student competencies across program implementation) and impact (e.g., sustained program integration into university culture and policies). Summative evaluation describes program accomplishments and program effectiveness [35], which will be informed by comparing retrospective and concurrent comparison groups with project cohorts. The summative evaluation includes pre- and post-measures aimed at detailing the degree of student learning achieved, mentor assessments of participating students, student retention in STEM programs, student academic performance and student tracking beyond graduation.

3.2. Assessment plan by evaluation question (EQ)

A mixed-methods approach employing quantitative and qualitative data from multiple stakeholders (students, faculty, and administrators) is used to answer five evaluation questions. EQ1, "To what extent is the traineeship model being developed as intended to address the skills training needed to prepare students for STEM careers?," is a formative question that will be answered by comparing the developmental network-based mentoring and career preparation activities specified in the curriculum to 12 key skills needed for STEM careers.

EQ2, "To what extent is the traineeship model being implemented as planned?," is a process evaluation question with two major foci. The first concerns the assessment of how well the program reaches its intended targets. Both number and breadth of students, faculty, and hosts will be assessed using data from recruitment and selection processes as well as academy activity attendance. Of particular interest is assessing participation of URM and academic departments. Participant diversity is expected to increase over time. Second, program component implementation will be measured including implementation of and feedback on required courses, mentoring (including peer) experiences, training, internships, and coaching. Data from course evaluations, academy activity and internship evaluation forms, focus group discussions, and pre- and post-test surveys as well as program activity attendance, course enrollment, and mentoring team constellation will be used.

EQ3, "To what extent are student and faculty competencies and interdisciplinary and transdisciplinary skills changing over the course of the training program? Additionally, to what extent are these changes reflected in longer-term outcomes?," is an outcome evaluation question focusing on competency, technical, and professional skills change over the program implementation. Data from or about NRT trainees, students attending open activities, and students receiving no program exposure (retrospective cohort) data will be compared using institutional research sources, faculty-administered student competency assessments, and survey data (collected at activities; pre- and post-surveys), as available. Additional data specific to NRT trainees include the number of proposal submissions and funded projects and faculty/ mentor rubric scores of trainees' work (solicitation review, dossiers).

EQ4, "To what extent are the project research activities being implemented as intended?," is a process evaluation question answered by the breadth of disciplines represented by faculty (core and recruited) and students involved in each research project and how well the project progresses toward its dissemination goals (symposia presentations, posters, publications, dissertations in discipline-specific, interdisciplinary and transdisciplinary outlets). Team composition and dossier review data will be used to answer this question.

EQ5, “In what ways (if any) are components of the training program integrated within academic programs, across programs, and at the institutional levels?,” is a sustainability/ impact question. First, data from administrators – at both university and department levels – will be used to evaluate institutionalization of program components. Benchmarks of sustainability include policy changes regarding network-based mentoring, transition of symposia and courses/ seminars from departmental to university-side sponsorship. Second, trainee alumni employment data will be used to document the extent to which trainees are recruited and employed by types of institutions serving as internship sites.

3.3. Analysis plan

Thematic analysis [36] will be conducted on all qualitative data (e.g., survey open-ended items, focus group discussions/ interviews). Coding will be iterative, review being followed by initial category generation and refinement [37]. Appropriate descriptive and inferential statistics will be used to analyze quantitative data. Descriptive statistics will be used to summarize quantitative data, including IR data, program exposure, competency development, academic performance, certificate completion, retention and graduation, as well as faculty and student skills development. Inferential statistics (e.g., hypothesis testing using mean differences) will be used to assess pre-to-post-to-follow-up quantitative changes for students and faculty. Longitudinal data analysis will examine patterns of change in each student cohort across time. A triangulated analysis of quantitative and qualitative data [38] will be conducted to answer evaluation questions and to examine the extent to which the NRT objectives are met. Ongoing feedback and recommendations will be given to the team to incorporate into training, curriculum development and other NRT activities.

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