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Online Undergraduate Research in Science, Technology, Engineering, and Mathematics Courses

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UNDERGRADUATE RESEARCH IN ONLINE, VIRTUAL, AND HYBRID COURSES

Proactive Practices for Distant Students

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ONLINE UNDERGRADUATE RESEARCH IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS COURSES

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What constitutes research can vary across fields. Even within science, technology, engineering, and mathematics (STEM) disciplines, the definition of *research* is flexible. For example, although science research and engineering research use similar methods and both produce valuable insights into the nature of our physical world, they have notably different focuses, with sciences aimed at expanding the outer edges of our knowledge and engineering fixed on systematic structuring of knowledge for application (National Academy of Engineering, 1995). Regardless of the STEM discipline, undergraduate research is a mentored experience in which students engage in original work, disseminating their outcomes to a larger audience through presentations or publications.

Engagement in undergraduate STEM research offers significant benefits, with students demonstrating STEM-related content knowledge gains (Stanford et al., 2017), identity development (Linn et al., 2015), and improvement of attitudes (Arnold et al., 2019). Undergraduate research increases persistence and retention, as Campbell argues in chapter 1, and increases diversity in STEM degrees (Bangera & Brownell, 2014). Credit-bearing undergraduate research experiences (such as course-based undergraduate research experiences [CUREs] and independent studies) may be an excellent strategy to counter the reduced persistence some researchers have observed in online STEM courses compared to the traditional classroom and to draw in minority students who have been shown to enroll at lower rates in online STEM courses (Wladis et al., 2015).

Despite the potential benefits to students, I have found that online students' knowledge of and interest in STEM undergraduate research opportunities may be limited (Faulconer et al., 2020). Even with limited knowledge of current opportunities, a survey of online undergraduate students across multiple disciplines at my institution showed that student interest strongly hinged on "if the right project comes along." Students reported favoring incentives such as a stipend or course credit (CURE or independent study). Barriers reported by students included knowing where to start, whom to contact, time commitment, and research cost. Time may be of particular concern at our institution because our online courses operate on a condensed 9-week semester length, as is common in online courses.

As noted in previous work (Downing & Holtz, 2018), my examination of the literature reveals the translation of undergraduate STEM research to the online classroom is relatively new, with only anecdotal studies published at this time. One cause of delayed adoption of this high-impact practice in online learning may be hiring trends. Many new faculty positions are not tenure line, and contingent faculty may be more likely to teach online courses. Furthermore, institutions may not give credit for tenure/promotion or compensate online research mentoring adequately to incentivize faculty participation (Green et al., 2009). For example, at my own institution, my faculty workload does not include independent study courses (regardless of online or traditional modality), which are handled as an overage and compensated with a small stipend. This suggests that time may be a barrier for both students *and* faculty. In addition, regardless of the modality of teaching, faculty may lack pedagogical knowledge for developing STEM research skills (Brew & Mantai, 2017); professional development may be a barrier for faculty. My institution has a distinct professional development office for each campus, including the fully online campus. However, this office has not yet offered professional development in undergraduate research. The residential campus undergraduate research office offers this level of professional development, but it is not currently advertised to distance faculty. Cumulatively, these factors may impact the development and offering of credit-bearing undergraduate research experiences in online STEM learning. The rest of the chapter outlines two online initiatives at Embry-Riddle: one not very successful and the other quite successful.

A STEM Independent Study

In 2018, I developed an upper-level independent study course to support the environmental science minor. The course is available to any student who has completed the introductory environmental science and research prerequisite courses. The course allows students the opportunity to choose research, service learning, or a special project. For this reason, the course is titled A Self-Directed Exploration of Environmental Science. As an asynchronous online course, the course structure is developed through the learning management system and is divided into nine modules.

Whichever path the student takes, the course is treated as a project. Therefore, modules are based on project management best practices. In Module 1, the design phase, students develop and finalize a project plan and prepare an annotated bibliography to support their work. In Module 2, the development phase, students prepare a literature review. Modules 3 through 7 are the implementation phase. Support includes setting subtask deadlines and addressing issues of time management, protecting data, scope creep, perseverance, accepting critical feedback, and quality standards. In Module 8, the communication phase, students focus on stakeholder communication of final project outcomes and dissemination of deliverables. In Module 9, the project closure phase, students demonstrate mastery of the learning outcomes they identified in their project plan and reflect on their development of key transferable skills.

If you build it, they will come, right? Unfortunately, that has not been the case here. I attempted to recruit students who were enrolled in the environmental courses through general announcements and emails as well as specific conversations with individual students via email. In addition, the independent study has been advertised in the quarterly newsletter for the environmental science minor. Finally, the credit-bearing research opportunity has been mentioned on the campus-level research web page. Despite these significant recruiting efforts and notable stated interest (reported in the previously described student survey), only three students have completed this independent study course. Two students opted for research, while the other student focused on service learning. (Although it is possible for some service-learning activities to fall under the category of action research, that was not the case with this student project as it focused on generating elementary-level curricular materials on specific environmental topics but did not evaluate these materials or otherwise generate data.) In one research project, the student collected and cataloged microplastics. In the other research project, the student performed a targeted literature review to identify key gaps in the literature and an ideal topic for a review article.

Anecdotally, the barriers to enrollment in the independent study course that students communicate to me include a poor understanding of what the course entails, a lack of time, and a perception that the course workload will be higher than a traditional course. In two separate instances, interested students approached me, but their projects required seed funding. Internal seed grants at my institution are not available to our online students. Funding is campus-specific, and the distance campus does not have a budget line to support undergraduate research at this time. This is despite online students composing 69.6% of the total student population at our institution in 2020 (although online students tend to be part-time whereas residential students tend to be full-time). If they were eligible, students would need to time their course enrollment and funding proposal carefully based on when proposals are due, when funds are dispersed, and when funds must be spent (or forfeited). This is a similar challenge faced by traditional students but may be particularly problematic for online students who enroll in condensed-term courses (e.g., 9 weeks compared to the traditional 16 weeks). This funding issue points to action I can take as a faculty member to advocate for funds earmarked for this population of students who contribute to enrollment and institutional revenue.

Whether a component of a CURE or an independent study, undergraduate STEM research is possible for geographically dispersed online students within a condensed term with (likely) no funding. Students could prepare technical writing (technical reports, white papers, or standard operating procedures) and professional writing (review articles or meta-analyses). Students can also access secondary data available in databases. Data sources for use in the Environmental Science Independent Study course include the U.S. Environmental Protection Agency's Toxics Release Inventory Pollution Prevention Program, the U.S. Department of Energy's Office of Scientific and Technical Information Data Explorer, the U.S. National Science Foundation's (NSF's) DataONE Data Catalog, the United Nation's UNdata, the Food and Agriculture Organization of the United Nation's Aquastat, or the World Wildlife Fund's HydroLAKES. Students can work with research-active faculty, taking on specific roles such as data analysis or project management. Citizen science projects such as Zooniverse, iNaturalist, and SciStarter can support virtual research projects. For example, a recent project from North Carolina State University used camera traps deployed by citizen scientists to investigate how urbanization increases species interaction, particularly regarding carnivore distribution (Parsons et al., 2019). With recent shifts due to COVID-19, even the NSF's Research Experience for Undergraduates programs may be offered remotely (Gadwal, 2020). It may be helpful to educate faculty on the potential for online undergraduate research using these types of resources to gain traction with online undergraduate students in STEM research. This outreach could come either through a professional development office or through an office of undergraduate research.

A Framework for Undergraduate Research in Online Engineering

Although my original independent study course remains an option for students to engage in undergraduate research, I recognized that a lone independent study that only served as an elective option in a minor would not garner large student interest, and my goal was to impact more students through systemic change. Therefore, I set out to identify the existing key supports to leverage to institutionalize undergraduate research at our distance campus. Our engineering technology degree is a popular choice, seeing strong enrollments and degree retention. At the distance campus, our engineering faculty have been successful in maintaining disciplinary research agendas. This is not the case for other applied and pure science faculty at our distance campus. Although my background is bench-scale environmental chemistry, I established a research agenda focusing on best practices in online STEM learning when I joined our distance campus in 2016. These two factors made the fully online accredited BS in engineering technology (BSET) an ideal target for establishing a support framework for undergraduate research for online students. This section describes the vision, structure, institutional supports, and other considerations that have gone into this framework.

It took 1 year to identify existing resources, propose modifications of existing resources, and detail supports needing to be developed, culminating in an external funding proposal. In 2020, the NSF's Improve Undergraduate STEM Education program funded the 3-year project to implement the framework in the BSET program at my institution. The goals are to increase students' retention and academic success through a structured undergraduate research program.

The framework includes scaffolding in four areas: early experiences, a bridge to research, undergraduate research, and culmination.

Early Experiences

The early experiences in the framework include an introductory research course and a research skills workshop. The Introduction to Research Methods course is a three-credit-hour course (taught asynchronously online) intended to equip 1st- and 2nd-year undergraduate students with basic research skills including defining a research problem, defining a hypothesis, problem-solving, knowledge discovery, literature reviews, designing appropriate methodology, quantitative and qualitative research methods, data analysis, evaluating outcomes, and communication of research results. This course is deeply enriched with transferable skills represented in the institution's general education competencies, including critical thinking, quantitative reasoning, information literacy, communication, and collaborative learning. This course teaches broad research skills and is therefore taught by faculty across many disciplines, spanning all colleges at my distance campus. Because this course walks students systematically through the research planning process, it is a logical starting point to bridge into actual undergraduate research. Many institutions offer an introductory research course, making this a transferable starting point for outreach and recruitment into undergraduate research across many programs.

The research skills workshops are non-credit-bearing, optional activities available to all online students regardless of degree program. Lasting for approximately 1 hour, they are hosted synchronously on a rotating schedule, although recordings are posted into an online platform that allows for asynchronous engagement with attendees and presenters. While presenters may be mentors or supervisors to a certain subset of students, the presenters are selected due to specific expertise in the area of the workshop. For example, a faculty member serving on a journal editorial board leads the "Getting Your Paper Noticed" workshop. The first research skills workshop in the series, titled "Formulating Your Research Vision," is advertised in the introductory research course and is available to all students, not just the target degree program. The workshop covers finding a research opportunity, selecting a mentor, and roles in a research team—with particular emphasis on roles suited to distant students. The workshop also provides key research points of contact and outlines institutional support for undergraduate research. This workshop targets three common barriers to undergraduate research that have been reported in previous student surveys: knowing what opportunities are available, knowing where to start, and finding time (Faulconer et al., 2020). Students can engage in workshops at each level of the framework, which is presented in a prescriptive sequence. Students tend to take the introductory research course in their 1st year and thus are likely to engage in the first workshop in their 1st year. Engagement in later workshops will depend on the stage in their undergraduate research journey. Faculty could consider incentivizing participation with course credit or extra credit, as appropriate.

Bridge to Research

The Bridge to Research in the framework is where students are recruited into a research track for their engineering technology degree. Although the degree previously offered 11 concentrations (e.g., aviation safety and unmanned aerial systems), there was not a research-focused option. Regardless of concentration, the new research track utilizes a three-credit-hour research independent study course in exchange for one elective course. Because poor curricular timing (e.g., sequencing) is a documented barrier to undergraduate research (Wayment & Dickson, 2008), the student and academic advisor work together during this Bridge to Research phase to establish the degree map for the student, appropriately timing the research independent study.

Once in a research track, students enter the Research Mentoring Program. This effort takes advantage of an existing mentorship program focused on career mentoring. There are established efforts for faculty professional development, faculty workload allocations, and program evaluation measures, making its adoption to this stage of the framework particularly helpful. The existing professional development offered from the residential campus's office of undergraduate research focused on best practices in mentoring. Content related to active mentoring practices (Davis & Jones, 2017) and mediated action approach (Palmer et al., 2015) was added to enrich the coverage on best practices in undergraduate research mentoring and online mentoring best practices. Institutions without existing research mentorship professional development, mentor and research supervision workload guidelines, and program evaluation measures will need additional planning and coordination before initiating this type of framework for undergraduate research support.

It is important to note that research mentors are not necessarily research supervisors. Research mentors for this framework (housed through an existing mentoring program) engage in a long-term relationship with students participating in undergraduate research, offering support to students through regular meetings. Mentors provide emotional and intellectual support to help students set expectations for the research experience, navigate hurdles along the path, and develop key research skills. Distinct from mentorship, the role of research supervisors is limited to engaging students during their 9-week research independent study course. The goal of research supervision is to support the completion of an undergraduate research project, including making a dissemination plan. Research supervisors support the student's project management, data analysis, and communication. Supervisors also ensure research proceeds safely. Research supervisors serve as a model of the nature of research. The nature of the supervisory relationship is more formal than the mentoring relationship, with the specific frequency of interaction related to the structure of the research independent study course. Both mentoring and supervision can improve student self-efficacy, confidence, and STEM identity by modeling how to do research and critiquing decisions made during the research process (Davis & Jones, 2017).

In the initial phase, the mentor sets clear and scaffolded expectations for undergraduate researchers. Early conversations center on research vision, the fit of research within an academic and professional career, and securing a research supervisor. Additional mentoring topics include student use of resources, research funding opportunities and deadlines, development of key research skills and techniques, and research dissemination options. This program aims to create a culture of collegiality by building a community of researchers and mentors, balancing expectations, and providing emotional and intellectual support (Johnson et al., 2015; Shanahan et al., 2015). Ideally, mentoring supports increasing student ownership of research over time. Mentors and mentees are given complete freedom to establish the formality and frequency of interaction because these factors have not been shown to impact perceived research skill mastery (Davis & Jones, 2017).

Prior to starting the undergraduate research experience, students have the opportunity to refine their research skills through the workshop titled “Honing Your Research Skills.” As with other workshops, this is available to all students, not just those in the target degree program. The workshop covers experimental design best practices, research ethics (including the institutional review board [IRB] and safety), the nature of research, and research project management. In a recent survey, faculty reported deficient student research skills as a significant barrier to their engagement in undergraduate research supervision regardless of modality (Faulconer et al., 2020).

Undergraduate Research

Students will work with their research mentor to identify an appropriate research supervisor to work with them through the Research Independent Study course. The course, taught by the selected supervisor, is designed through the application of CURE best practices that include the scientific and engineering best practices of supporting discovery, generating broadly relevant work, fostering collaboration, and allowing for iteration (Auchincloss et al., 2014). The course is structured in three units with multiple milestones. In Unit 1, students prepare (a) a literature review with emphasis on critical appraisal and synthesis, (b) an experimental design with emphasis on safety, and (c) a project management chart (e.g., Gantt) to manage deadlines and milestones. This unit also explores both the mentor–mentee and the supervisor–supervisee relationship, roadblocks and research reality, and the nature of science in research. In Unit 2, students launch their research while performing self-reflection through journaling about managing change, setting expectations, and critical perseverance. This unit also introduces more key research skills. Students learn how to get their message across through narrative, titling, and graphical abstracts. The second unit also supports student evaluation of publishing venues, including consideration of scope, bibliometrics (e.g., Impact Factor and CiteScore), open access, predatory journals, copyright, publishing fees, formatting software options (e.g., LaTeX), and journal processes. In Unit 3, students are wrapping up their investigations and receive support in research statistics, data visualization, and responding to peer review. Research ethics are emphasized, covering author guidelines, coauthor contributions, acknowledgments, funding disclosure, conflict of interest, plagiarism, bad science, and dual submission. The course ends with a culminating self-reflective journaling activity.

Examples of undergraduate research projects (performed both in credit-bearing courses and independently) completed by fully online students include researching current sizing and performance characteristics of small unmanned aircraft systems (sUASs), analysis of sUAS flight testing protocols and data, and development of resources in the Embry-Riddle Aeronautical University (ERAU) Virtual Hub (an interactive simulation tool to explore the elements, design, and function of aircraft systems, including the Virtual Crash Lab, which allows an interactive virtual inspection of a crashed Boeing 737). Additionally, some students worked with publicly available, published performance data for commercially off-the-shelf, fixed-wing, and vertical takeoff and landing unmanned aircraft systems to develop statistical models. Research in this area has notable implications for emergency response, disaster relief, precision agriculture, security, communications, environmental monitoring, infrastructure inspection, cargo delivery, and mapping. It is important to note that even online students have a strong desire for hands-on research experiences (Faulconer et al., 2020).

Dissemination of undergraduate research results is supported both internally and externally. Online students have the opportunity to present their research at an annual face-to-face event called "Discovery Day" using synchronous virtual technology. External dissemination at regional and national conferences can be supported through internal travel grants. Students can also seek publication through my institution's peer-reviewed journal, *Beyond: Undergraduate Research Journal*. Finally, students can work with their research supervisor and research mentor to publish through external venues such as the *Journal of Young Investigators* or appropriate disciplinary venues.

Two additional research skills workshops support students in the undergraduate research phase. The first one, titled "Submission and Review Gauntlet," covers why articles are rejected, options if rejected, and responding to reviewer and editor feedback. The second workshop, titled "Getting Your Paper Noticed," addresses search engine optimization, LinkedIn, Scholarly Commons, and other mechanisms to increase the visibility and impact of published works.

Culmination

Students who have completed their research are supported with two additional research skills workshops, with one centering on research next steps (thesis or dissertation building and entrepreneurial ventures) and the other guiding students in promoting their undergraduate research experiences in their résumés.

Students who have completed the research track of the BSET degree can apply for an undergraduate research certificate and receive a digital certificate of completion. They receive recognition at institutional events, recognition on the institution's undergraduate research website, and a pin to be worn with graduation regalia. Requirements to earn the certificate are to (a) complete at least one semester of faculty-supervised research, demonstrating "mastery" for all research learning outcomes in the research independent study course, (b) disseminate at least one artifact of original research via conference participation or publication in a peer-reviewed journal, (c) complete relevant research training (participate in four or more research skills workshops), and (d) obtain a letter of recommendation from the research mentor or research supervisor that specifically documents student–faculty interactions and student progress on one or more research learning outcomes.

Additional Support

Students can gain additional support relevant to research communication (oral and written) through the institution's Virtual Communication Lab (VCL), managed through the College of Arts and Sciences by full-time faculty members, with faculty tutors compensated through a course release and student tutors paid hourly. The VCL offers one-on-one tutoring, feedback, and workshops for research activities such as literature reviews and synthesis as well as research deliverables, including practice sessions for oral and poster presentations. Access to this support occurs at all stages of the framework.

For consistency in student expectations, the framework is built on six undergraduate research learning outcomes covering the articulation of a research problem, research design, research ethics, independent and collaborative research activities, analysis and conclusions, and communication. These research learning outcomes are consistent across the institution. A rubric describes performance from novice to mastery level. These learning outcomes are introduced in the Introduction to Research course, with students' performance expected at the "novice" and "introductory" levels. These learning outcomes form the independent study course structure, and performance is expected at the "practicing" and "mastery" levels. They are further infused in the research skills workshops and interactions with research mentors.

Undergraduate research mentorship and supervision have implications for faculty workload. Notable obstacles for faculty involvement in undergraduate research are time and decreased productivity—with associated challenges for meeting promotion milestones (Lunsford et al., 2013). Furthermore, faculty may not receive credit for their undergraduate research supervision or mentorship efforts in promotion and tenure decisions. By recruiting research-active faculty into the undergraduate research role using an existing mentoring program, faculty workload implications for research mentorship did not need to be addressed. Undergraduate mentorship is recognized institutionally as faculty contribution in the area of college-level service and acknowledged as a significant activity that provides notable benefit to our students.

In contrast to the system for workload credit for research mentorship, without an existing program and associated guidelines, the implications of undergraduate research supervision at my institution are negotiated on a case-by-case basis between faculty and their direct supervisor. Faculty must navigate implications of any reduced productivity on their promotion and tenure. However, our current institutional strategic initiatives identify the need to recognize the workload and the impacts of research supervision on faculty evaluations, promotion, and tenure. Hopefully, this means that there will be formal guidelines for the recognition of undergraduate research supervision efforts by faculty in the near future.

Conclusion

Undergraduate research experience in engineering has been shown to have long-lasting impacts on students, including the formation of meaningful relationships with faculty, an increased pursuit of graduate degrees, and a growth in transferable skills, both cognitive and personal (Zydney et al., 2002). Although there are some unique challenges to offering undergraduate STEM research opportunities to online and distance students, it is important to provide this high-impact practice to all students.

According to best practices, online undergraduate research opportunities within STEM should use outreach, support online-only and hands-on research opportunities, offer development opportunities for students and faculty, and provide research mentorship and communication-related tutoring and the option for institutional recognition. These actions are likely to improve student learning, persistence, and retention. I believe we can change the expectation of what is possible for distance students, breaking stereotypes about online STEM education.

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