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UNDERGRADUATE RESEARCH AND CLIMATE CHANGE

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Lindsay Currie, Executive Officer
267 Kentlands Boulevard, No. 4021
Gaithersburg, MD 20878
Tel: 202-783-4810; Fax: 202-783-4811
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Undergraduate Research and Climate Change

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Introduction

Lisa Gates, *issue editor*

Undergraduate Research and Climate Change

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The signs of active climate change are everywhere. On June 29, 2021, the highest-ever temperature was recorded in Lytton, Canada: 121.4°F; fire later decimated the village. The Bootleg fire in Oregon has been eclipsed by the Dixie fire in California as the largest in the United States; each has burned more than 400,000 acres. The death toll from July's catastrophic floods in Germany and Belgium hovers around 200. A flash flood in Zhengzhou, China, a city located on the Yellow River, trapped more than 500 subway riders for hours. Climate change is an exigent problem, presenting challenges in transforming energy systems and agricultural practices, rethinking political structures and international cooperation, and addressing climate-induced migration. Such a difficult and daunting reality requires educators to engage students in this work, as they will be the problem solvers and changemakers for the coming decades. In this themed issue of SPUR, the authors explore their methods for infusing climate change impacts into classroom and research experiences.

This issue features two practice articles that highlight the importance and impact of integrating climate change work across fields. Sarah Whipple (Colorado State University) and colleagues discuss a US-Australia project integrating sustainable development goals established by the United Nations into courses and project-based learning opportunities. The UN's Sustainable Development Goals—or SDGs—offer a blueprint for a sustainable future. By creating research teams focused on one or more SDGs, the authors bridge the gulf between science and policy as well as study and action. The multidisciplinary, multi-institutional dimension of the project engenders a broader sense of community among students and faculty, helping students develop the interdisciplinary communication and leadership skills essential for addressing climate change.

Moving to the Arctic region, Arnell Garrett (Delmarva Analysis) and colleagues discuss the Polaris Project, initiated in Siberia and now operated in Alaska. Designed to increase the engagement of historically underrepresented groups in climate science and Arctic research, Garrett and colleagues have developed a robust Research Experiences for Undergraduates (REU) program with the Woodwell Climate Research Center that introduces students to Arctic science through virtual and in-person meetings, summer fieldwork, and a culminating poster presentation. More than 95 percent of the REU participants come from backgrounds underrepresented in Arctic science. Mentoring by faculty of diverse backgrounds from multiple disciplines is a key part of the program's success. Assessment data document an increase in participant self-efficacy—a trait key to persistence in STEM.

This issue also includes four vignettes that illustrate various undergraduate research applications to climate change. Laura Guertin (Penn State Brandywine) and colleagues discuss the use of a scaffolded audio-narrative project in their introductory earth sciences course that engages students with ongoing projects developing climate solutions and assists in building multiple literacies—informational, digital, and scientific—in the process. To help students understand the complexity of climate change—its roots, impacts, and solutions—Thomas Hickmann (Utrecht University, The Netherlands) has developed a simulation game based on the international climate negotiations he observed at several UN climate change conferences. Hickmann uses this game in courses to help students understand the difficulty in accomplishing collective action on climate change issues and the exacerbating effects of wealth and power disparities and political instability. Robert Nazarian (Fairfield University) discusses his use of data from publicly available computational model intercomparison projects (MIPs) in laboratory work with undergraduates to convey the effects of climate change. These rich data sources allow students to analyze areas of impact to physical, biological, and social systems as well as increase their contextual knowledge, engendering new collaborations with other researchers and nonprofit organizations. Tara Kulkarni (Norwich University) describes the long-standing service-learning component of an introductory environmental engineering course. For almost a decade, students in the course have developed models to demonstrate environmental challenges and solutions, sharing those models with members of the local community such as K–8 students, thus communicating the significance of their research to a much broader audience.

Although the challenges posed by climate change are indeed daunting, these authors provide insight on the effective integration of specific methods and projects—large and small—into undergraduate research that can help prepare students for the climate change-related challenges they will face in their professional and personal lives.

PRACTICE

Engaging the Youth Environmental Alliance in Higher Education to Achieve the Sustainable Development Goals

Sarah Whipple, *Colorado State University*
Shardul Tiwari, *Michigan Technological University*
Tashiana C. Osborne, *University of California–San Diego*
Gillian Bowser, *Colorado State University*
Sarah A. Green, *Michigan Technological University*
Pamela H. Templer, *Boston University*
Susie S. Ho, *Monash University*

Abstract

The authors present a new approach to show how interdisciplinary collaborations among a group of institutions can provide a unique opportunity for students to engage across the science-policy nexus using the framework of the Sustainable Development Goals and the United Nations Framework Convention on Climate Change. Through collaboration across seven higher education institutions in the United States and Australia, virtual student research teams worked together across disciplines such as economics, ecology, and other earth and social sciences to address research questions centered on sustainable development goals. The teams presented their findings in person to diplomats and delegates at the 2019 United Nations Conference of the Parties meeting in Madrid, which also had strong qualitative impacts on their perceptions of international science-policy interfaces.

Keywords: *international negotiations, science communication, student learning, sustainable development goals, transdisciplinary partnerships, virtual learning*

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Environmental issues associated with international sustainability are multi-scaled, transdisciplinary, and interconnected, yet few programs at individual academic institutions have the breadth of expertise to incorporate all these challenges simultaneously into the undergraduate or graduate education experience (Bowser et al. 2020). Undergraduate students studying life, geophysical, and environmental sciences often learn from their courses about the myriad ways in which humans impact the environmental systems they study. The impulse of many students is to "do something" about these issues, yet the typical science curriculum does not provide them with the tools and skills necessary to address environmental concerns and associated policies at local, regional, and global scales (O'Malley 2019). As student interests in sustainability increase, it is important to also provide them with the tools needed to pursue careers that contribute to and encourage environmentally targeted solutions while crossing multiple sectors (e.g., academia, business, government, nongovernmental organizations, and civil society; Fenn et al. 2010).

Past research shows that students benefit the most in interdisciplinary training when they collaborate with peers and are directly engaged in tangible actions, including the dynamic science-policy nexus (Archer 2011; Halliwell and Bowser 2019). In addition, the benefits of peer teamwork have been identified as tools to engage a broader student demographic; create spaces of belonging; and build student scholarly identity, self-efficacy, and confidence. Student members of multicultural, multi-institutional teams often report such sentiments of belonging and science identity associated with maintaining a common purpose and scientific agenda among a team of peers (Armstrong et al. 2007; Bowser et al. 2014; Fenn et al. 2010; Freeman, Anderman, and Jensen 2007; Halliwell and Bowser 2019; Walton and Cohen 2011). These outcomes potentially contribute to higher retention rates of students in underrepresented groups in science fields (Bowser et al. 2012; Cid and Bowser 2015; Walton and Cohen 2011).

Collaborations in both virtual and in-person settings are common in the professional and scientific workplace to enable the study of multiscale phenomena across local and global scales (Atkins et al. 2003). International partnerships and team research have dramatically increased among researchers and faculty as the accessibility of smart devices, applications, and workspaces used to create collaborative networks has increased. Such collaborations, however, are less common for students in academia. Students are often less likely to have opportunities to both learn from and contribute to experiences working with peers from different countries or ethnic, racial, or cultural backgrounds.

Universities have begun to incorporate the United Nations Sustainable Development Goals (SDGs; see Table 1 for a subset of goals) and the United Nations Framework Convention on Climate Change (UNFCCC) as a pedagogical structure for science-policy courses, campus climate initiatives, research projects, and modeling scenarios (Beynaghi et al. 2016; Salvia et al. 2019). The Brundtland Commission (1987) first defined sustainable development as efforts that "[meet] the needs of the present without compromising the ability of future generations to meet their own needs." The 1992 Rio Earth Summit was considered one of the first formal international gatherings to present climate science and society goals as key interconnected elements for structuring and advancing actions and goals toward sustainable development as articulated by the commission. Two decades later, in 2012, at the Rio+20 Summit—also held in Rio de Janeiro—the UN presented the 17 SDGs, designed as enhanced successors to the Millennium Development Goals (MDGs; Kumar, Kumar, and Vivekadhish 2016; United Nations 2012). The previous eight MDGs had encouraged increased health, environmental sustainability measures, and access to primary education and technology worldwide but also came with limitations involving accountability, causes of inequities, and the interconnectedness and implementation of goals (Bue and Klasen 2013; Fehling, Nelson, and Venkatapuram 2013).

In 2012, the UN Conference on Sustainable Development (Rio+20 Summit) crystallized connections between social equity and environmental sustainability as international strategies. "The Future We Want," a negotiated outcome document of the summit, first described SDGs as next-generation priorities (UNGA 2012). With the adoption of the SDG framework by the UN General Assembly in 2014, international negotiation bodies and funding mechanisms have since used the strengthened goals and targets for research direction and actions (UNFCCC n.d.). Key elements necessary to achieve SDGs include holistically assessing and addressing underlying causes of inequities and inequalities (Lusseau and Mancini 2019). This can be modeled by encouraging and integrating equity-centered, community-tailored approaches, as outlined throughout UNFCCC proceedings and the advancement and implementation of the SDGs (Ferrer et al. 2021).

There have been some large-scale initiatives to involve students in SDG-related environmental work, such as the UN Environment Programme's "Green Nudges" program, but many of these efforts focus on a single campus and its internal efforts or research projects within a university or discipline (Abbonizio and Ho 2020; Fleacă, Fleacă, and Maiduc 2018). The authors are unaware of previous SDG-guided efforts on college or university campuses that have involved project-based collaborative learning initiatives that encourage students to become international, interdisciplinary change agents themselves.

Because of the need for greater solution-oriented training at the science-policy interface, the authors launched the Youth Environment Alliance in Higher Education (YEAH) in 2019 as a multi-institution research coordination network, with the goal of providing students with real-world experience in collaborative, evidence-based approaches to global sustainability by incorporating the SDG framework into higher education programs (YEAH 2020).

Youth Environmental Alliance in Higher Education

The SDGs, introduced in 2014 as a global framework including both social and environmental targets, provide a robust road map for training the next generation of leaders (Hess and Maki 2019) but require creative and innovative solutions developed across the boundaries of disciplines, countries, and sectors (Adger et al. 2013; Crate 2011; Gardiner 2006; Paul 2008). Yet within the academy many students are unaware of the SDGs and how this framework impacts international negotiations. Many also are unaware of ways in which a diverse range of stakeholders, including scientists, contribute SDG-relevant findings to inform policy content and processes. Despite the high profile of UN international science teams such as the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and additional predominantly virtual groups, the intersections of policy, science, and sustainability remain opaque to most students studying environmental sciences.

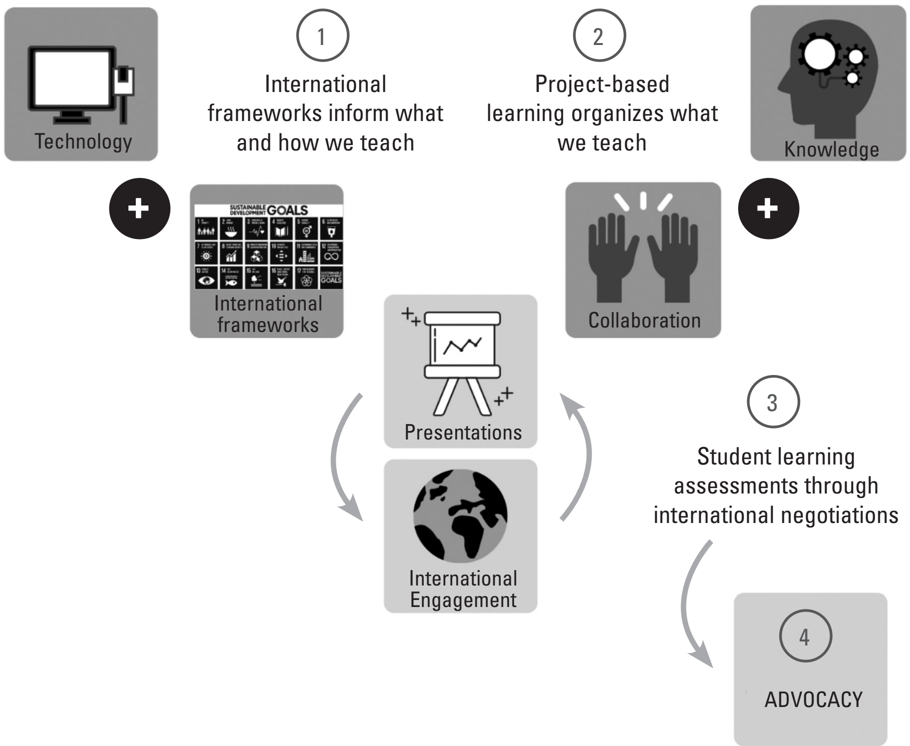
In 2019, YEAH piloted a virtual learning experience with seven institutions based in a variety of science disciplines, including ecosystem science, biological sciences, chemistry, atmospheric sciences, and social sciences. Educators, professors, and mentors participating in the 2019 YEAH pilot were from Colorado State University, Clark University, Michigan Technological University, Colorado College, Boston University, Monash University, and Scripps Institution of Oceanography at the University of California–San Diego (Scripps at UC San Diego). Using structured virtual

TABLE 1. Overview of Student SDG Teams and Projects

Team structure	SDG	SDG target	Study topics
-Team Lead: Scripps at UC San Diego -3 Undergraduates -4 Graduates	2 ZERO HUNGER	2-4: Sustainable food production and resilient agricultural practices	Composting, food secruity & zero-waste efforts on US campuses
-Team Lead: Colorado State University -2 Undergraduates -2 Graduates	5 GENDER EQUALITY	5-5: Ensure full participation in leadership and decision-making	Women leaders on US campuses need more support
-Team Lead: Clark University -4 Undergraduates -2 Graduates	6 CLEAN WATER AND SANITATION	6-6: protect and restore water-related ecosystems	Watershed restoration in the Great Lakes region, US
-Team Lead: Michigan Tech University -2 Undergraduates -4 Graduates	7 AFFORDABLE AND CLEAN ENERGY	7-A: promote access to research, technology, and investments in clean energy	Economic feasibility of renewables on US university campuses
-Team Lead: Colorado State University -2 Undergraduates -1 Graduate	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	9-4: upgrade all industries and infrastructures for sustainability	Innovative building efforts on US campuses
-Team Lead: Michigan Tech University -2 Undergraduates -4 Graduates	11 SUSTAINABLE CITIES AND COMMUNITIES	11-7: provide access to safe and inclusive green and public spaces	Sustainable housing efforts on Michigan Tech campus
-Team Lead: Colorado State University -4 Undergraduates -2 Graduates	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	12-5: substantially reduce waste generation	Sustainability perceptions of college campuses
-Team Lead: Colorado State University -4 Undergraduates -1 Graduate	13 CLIMATE ACTION	13-2: integrate climate change measures into policies and planning	Mountain ecosystems and adaptations on a global scale

Note: SDG = UN Sustainable Development Goals. The student team structure includes team-selected SDGs and SDG targets, and study topics presented during UNFCCC COP25 proceedings (Breidenbach et al. 2019; Carver et al. 2019; Colorado State University et al. 2019; Osborne et al. 2019; Stone et al. 2019).

FIGURE 1. Framework for the YEAH Network



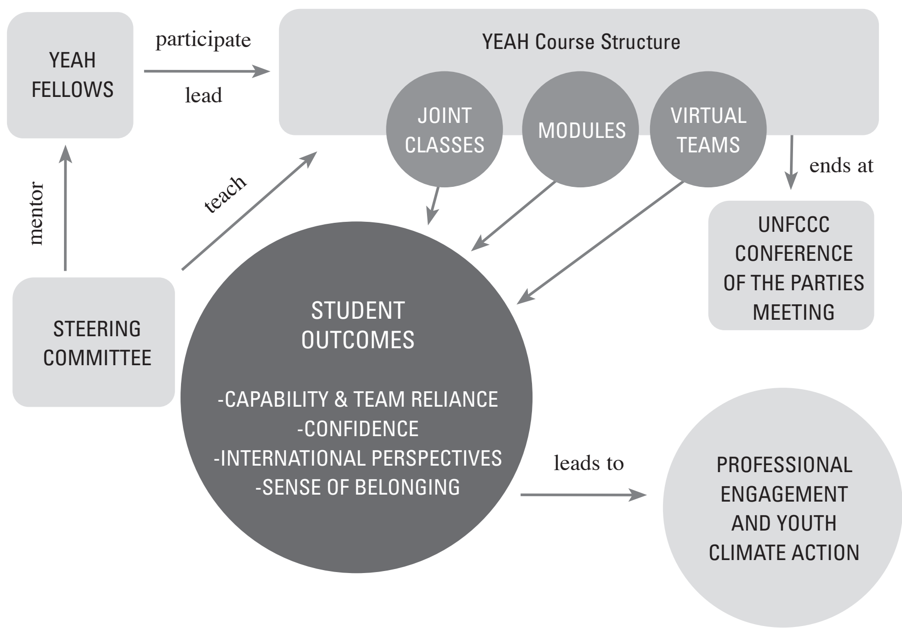
teams, mixed delivery, and engaging learning approaches, YEAH piloted an innovative teaching environment in 2020 guided by international frameworks including the SDGs and technological tools that informed classroom teaching. YEAH organized this environment to encourage collaborative team efforts that involved knowledge sharing across disciplines and institutions and encouraged both instructor-student and peer learning. Team efforts were assessed based upon student presentations at the 25th UNFCCC Conference of the Parties (COP25) in Madrid and the practical application of acquired knowledge and tools to support professional experiences in international climate negotiation settings. Last, collaborations and firsthand UN experiences translated into long-term climate and environmental advocacy efforts through individual and team-based translations of frameworks, classroom lessons, and experiences (see Figure 1; Brewer and Smith 2011).

Methods

YEAH was structured to bring hybrid approaches (combined virtual and in-person teams of students) to curriculum and project-based learning opportunities. This structure was designed to lead to final products presented at the COP25 meeting at the end of each academic semester. Figure 2 represents the overall structure of YEAH, including the steering committee that directed resources and assessments and the YEAH fellows, who were selected graduate and undergraduate students devoted to learning and academic research associated with international environmental issues. The YEAH course structure consisted of classroom instruction (primarily through online platforms), virtual team projects, and modules based on international negotiations and the SDGs. The common learning objectives across YEAH courses included: (1) linking cultural connections, sustainability, economics, development, and natural resources topics with international negotiations on climate issues; (2) developing team projects with students from participating institutions by working remotely and in person on international environmental topics; (3) understanding the processes of the UNFCCC; (4) articulating interdisciplinary (or cross-disciplinary) science topics to an international audience consisting of policy makers and stakeholders; (5) demonstrating understanding of the negotiation process, the Paris Agreement, and associated negotiations; and (6) participating in interinstitutional teams at the UNFCCC COP25 in Madrid.

Classroom instruction coupled with team-based learning composed the core concepts aimed at enhancing potential student-focused outcomes, such as improved teamwork capabilities (including the ability to engage with diverse stakeholders outside science), confidence, international perspectives, and a sense of belonging within one's educational field. These outcomes support students during international negotiation experiences and during further efforts

FIGURE 2. Internal YEAH Network Structure



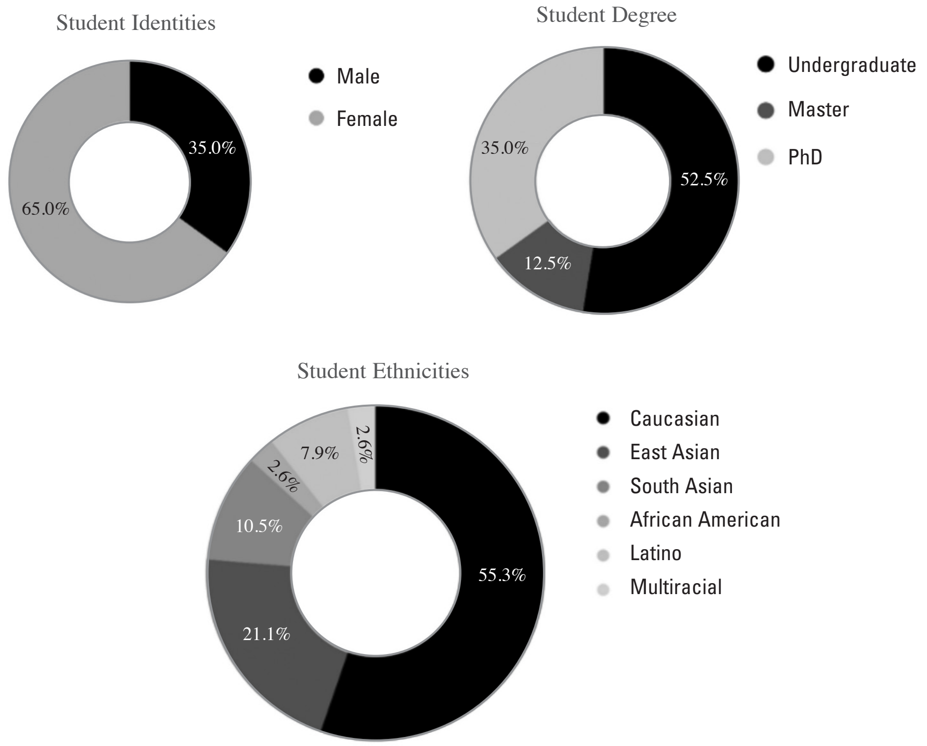
emphasizing climate action. The hybrid one-semester class included fourth-year undergraduate, master's, and PhD students representing a wide range of interests, including environmental sciences and sustainability, environmental policy, energy policy, atmospheric sciences, environmental planning, and anthropology. Most participating institutions targeted undergraduates when listing the course, resulting in 52.5 percent of course participants identifying as undergraduates, 12.5 percent as master's students, and 35 percent as PhD students (see Figure 3). The notable inclusion of graduate students is indicative of a demand for graduate student learning opportunities within the climate policy professional sphere.

The lead institution for each class meeting facilitated the virtual weekly meeting with the other students (47 students from seven institutions), guest speakers, and faculty using Zoom and shared slides. The course syllabus included an overview of the UNFCCC structure and function, international scientific reports (e.g., IPBES 2019; IPCC 2019), and policy negotiation topics and strategies. Students self-selected into nine multi-institutional, cross-disciplinary SDG teams, each of which developed and researched its own case studies centered on interconnected and individual SDGs. Student teams coordinated their group meetings, working deadlines, and final presentations. Instructors supplied educational materials and training during lectures, provided feedback as students gathered and analyzed information and created team presentations, and helped facilitate opportunities for students to present at COP25 events well-suited for individual projects.

Each team project included an undergraduate moderator and/or graduate student mentor, some of whom had prior experiences in the science-policy realm or had previously participated in a COP. Student moderators and peer mentors helped with research development, group meeting structure and timelines, final presentations, and preparations for the Conference of the Parties, including contextualizing the science with a wider policy lens, suitable for an audience of stakeholders from all areas of government and industry. However, the work of each team was network-based rather than hierarchical, with each group following the principle of "common but differentiated responsibilities." All teams completed the semester with professional presentations and press conferences at COP25 in Madrid.

Prior to the start of YEAH course instruction, participating instructors conducted a preliminary assessment centered on student interpretation and comprehension of course content (e.g., climate change science and policy, SDG framework). Also included were topics focusing on skills and tools necessary to grow and succeed as boundary spanners (or knowledge brokers) between science, various audiences (e.g., university campuses, local constituents, youths, decision makers, researchers, and media representatives), and policy (e.g., at international negotiations). Student learning outcomes were tracked using a qualitative evaluation survey that posed questions involving students' pre- and post-course experiences. The survey was designed to help gauge student perceptions of their team project outcomes as well as the knowledge they acquired during the online course, and the expectations

FIGURE 3. YEAH 2019 Student Demographics



Note: In this analysis, 4+1-degree program students were characterized as undergraduates and included in the same category as traditional undergraduate students. $n = 47$.

they had for the conference and final presentation. Additionally, to evaluate perceptions of the SDG framework in higher education settings within a broader population, an anonymous climate action survey was administered to participating students, researchers, and others present at COP25. All survey data were analyzed using the Statistical Package for the Social Sciences (SPSS). Post-course reflective statements were solicited from selected students who had demonstrated strong leadership within their team throughout the semester and during COP25.

Results

Forty-seven students from seven institutions participated during COP25, presenting at two official side events (speaking platforms for admitted observers to share knowledge across organizations) and seven press conferences. In addition, students created booth exhibits on their case study research, gave interviews to the press, participated in SDG-specific meetings of nongovernmental organizations, observed formal UNFCCC negotiations, and networked with international peers and organizations. Last, students collaborated on official statements on behalf of research and independent nongovernmental organizations and shared their notes and experiences during daily UNFCCC-wide youth and research constituency debriefs.

Based on student feedback and engagement, the successful completion and dissemination of student presentations, and long-term partnerships initiated during COP25, outcomes of the YEAH pilot exceeded all expectations. Examples of case study projects that achieved learning objective 6 (i.e., participation in interinstitutional teams at COP25) included the study of composting on college campuses, campus renewable energy, and economic sustainability of institutional resources (see Table 1; Breidenbach et al. 2019; Carver et al. 2019; Colorado State University et al. 2019; Osborne et al. 2019; Stone et al. 2019).

YEAH demonstrated an innovative approach to creating cross-institution virtual modules to train students in international scientific diplomacy using multidisciplinary and multicultural teams. Qualitative results from student collaborations using the YEAH hybrid approach demonstrated that the project-based learning framework led to improved understanding of multidisciplinary topics and increased student prowess in communicating science topics to stakeholders at an international scale. Further, application of this framework resulted in broadened participation at the Conference of the Parties among women and underrepresented minorities from different institutions, improved well-being and sense of belonging among underrepresented students participating in international discussions and activities, and an enhanced understanding of the science-policy nexus and the role of science in policy negotiations (Ng 2020; see Table 2). Based on the pre- versus post-experience assessments from students who attended the international negotiations in person, student understanding and articulation of climate science and policy efforts changed. For instance, out of those that completed the pre- versus post-experience assessment, students conveyed interest in continuing their participation in international environmental policy and attending future United Nations meetings on post-experience surveys and in focus groups. As revealed in Figure 4 (A and B), "engagement" was more prominent in the post-experience survey. One student stated that the experience of the pilot project was "mind blowing," and another expressed that they wanted "to share the experience with colleagues back on campus to get more involved in climate actions." Students expressed stronger motivations for activism efforts after their conference experience. In addition, the well-being of students improved as a result of explicit efforts to promote a sense of belonging through team-building activities that occurred both virtually and in person.

Discussion

The Sustainable Development Goals are a widely accepted international framework that is directly applied to academic instruction for students in science disciplines. By using the SDGs as scaffolding for project-based learning in a hybrid class, students in the YEAH network learned critical thinking skills and peer teamwork and gained a unique perspective on multicultural and multi-stakeholder audiences. The SDGs provided a common language that immediately linked the student's own projects to the wider conversations and negotiations taking place in United Nations environmental negotiations, such as the annual Framework Convention on Climate Change Conference of the Parties (COP). The universal nature of the SDGs, with well-defined metrics and targets, also increased the ability to design projects across academic levels (from undergraduate to graduate). The fact that student team projects and presentations incorporated the SDG icons, targets, and goals also created a common language for students to discuss their efforts with international negotiators, diplomats, researchers, and peers.

The YEAH project-based course has become a foundation for using the SDGs within the classroom for a growing group of institutions. Eleven institutions are now members of YEAH, with six classes projected to participate in the course in the upcoming year. Students involved in YEAH have increased their ability to participate in international negotiations centered around sustainable development. Although none of the students came into YEAH with a comprehensive understanding of the SDGs, all successfully utilized the SDG framework, translated SDGs and SDG targets to their science disciplines, and provided personal suggestions for future climate action. Moreover, students developed a sense of ownership and agency throughout the team project development stages and the final presentations, emphasizing the willpower and capacity with which these students formulated their own solutions to SDG targets.

Multicultural, international, and cross-institutional virtual and in-person teams such as those fostered through YEAH are becoming increasingly common in various research fields and are necessary to holistically understand and address climate change, environmental concerns, and additional issues that have societal impact. Additionally, previous studies have demonstrated the importance of emphasizing linkages between scientific research and the societal good to attract more diverse student cohorts into science disciplines (Armstrong et al. 2007; Halliwell and Bowser 2019; Stoepler and Bowser 2018). Furthermore, studies have shown that interdisciplinary and cross-sector work that prioritizes collaboration is becoming fundamental for succeeding in sustainability professions (Brown, Deletic, and Wong 2015). This study's cross-institution and cross-discipline teams introduced diverse students to science disciplines as well as social and policy disciplines and provided them with a critical sense of belonging to both a team and an international network with many diverse voices. The YEAH project provided tools and skill-strengthening experiences to increase students' understanding, proficiencies, and confidence as collaborators within an international setting and as communicators with a diverse range of stakeholders with the goal of addressing complex problems that cannot be solved by one country or discipline alone.

The impact of COVID-19 on international gatherings in 2020, including UN negotiations, was profound. As 2019 and 2020 were pilot years for YEAH, more data are needed to potentially reaffirm the impact that international negotiation participation can have on students when negotiations resume in 2021. Although the participation of students from the 2019 YEAH cohort in future climate negotiations is uncertain given changes to virtual formats and restricted gatherings post-COVID, qualitative survey responses suggest that students left the experience with an elevated understanding of the negotiation process and the complexities of global climate policy and consensus and with a deeper desire to take action with other youth across the world.

Conclusions

Policy negotiators will continue to face challenges as the world grapples with global pandemics, root causes of inequities, technological advancements, and changes in political regimes that may not be well captured or addressed within current climate agreements. Nevertheless, the

TABLE 2. Qualitative Examples of Student Learning Gains Highlighted by Pre- and Post-Experience Surveys and Focus Groups

Learning gain example	Pre-YEAH experience	Post-YEAH experience (immediate)	Post-YEAH experience (six months)
Understanding of multidisciplinary topics	"I anticipate learning about the multiple key sectors that are working toward climate change mitigation and the various approaches that they are taking. As a civil engineer, my learning focus will be on water resources management approaches and impacts to water resources due to climate change." —Male graduate student, US	"A lot was learnt, the main for me is the role of stakeholders, citizens and communities in adapting and mitigating climate emergency." —Male graduate student, US	"I love that action is produced by people all around the world, it's very multidisciplinary and collaborative. So, I admire that we're producing science that isn't coming from one place, or one type of people." —Female undergraduate student, US "I see a shift in science, and there are more and more interdisciplinary groups, people from other sectors of sciences and other countries working together. And that's something that is widely recognized now that there's a need to work [across disciplines]." —Female undergraduate student, US "In terms of what I was expecting from [the Conference of the Parties], I did expect to see interdisciplinarity and, in fact, I was really excited to say that was [there]. I definitely wanted to see how this works in practice." —Female graduate student, Australia
Science communication skills	"I do not expect to have a direct impact [on the meetings], but indirectly through side event presentations, conversations, and media outreach. I think contributing to the collective youth voice will help others hear and become familiarized with youth perspectives on key negotiation issues." —Female graduate student, US	"I hope that I could influence the outcomes of this meeting by reminding the negotiators that our future is in their hands and we care deeply about protecting our future and our planet." —Female graduate student, US	
Broadened participation	[negotiations need] "More communication with people from different cultures." —Male undergraduate student, US	"The ability to engage with so many different people across the world felt really valuable." —Male undergraduate student, US	"Youth engagement is absolutely crucial. We are the future generation. We are the future experts. We are the future policymakers. We are the future leaders. We have a voice and I feel our voice was taken seriously at [the Conference of the Parties] and I also feel that there is a shift in respect for youth, as the younger generations become more and more educated in these topics in the age of information." —Female graduate student, Australia "On a personal side, it was great. I mean, Greta [Thunberg] was there. And we also went to different protests [in Madrid to demand climate action]. And [that] was an amazing experience." —Female undergraduate student, US

(*table continues*)

TABLE 2. (cont.)

Learning gain example	Pre-YEAH experience	Post-YEAH experience (immediate)	Post-YEAH experience (six months)
Sense of belonging	"I feel that as a youth I had more of an observer role in this process overall, so that I can bring back what I learned to my peers at school and at home." —Female undergraduate student, US	"The youth can be more engaged by allowing more discussions on scientific research from universities across the world. This is where more youth can be co-opted." —Female undergraduate student, US	
Understanding of the science-policy nexus and science's role	"Hopefully some hope and passion—reinvigorating others that these goals are attainable if we can all work together! Little less lofty, but just a different perspective towards environmental policy—since this is my first [Conference of the Parties], I want to convey all my 'unknowns' to the negotiators to encourage transparency in their policy." —Female graduate student, Australia	"By raising awareness and speaking to leaders through our action and presence, I expected to make it clear that we need change—now!—by connecting our demand for change to scientific research, I expected to increase our credibility and influence the perceptions held by those who make decisions." —Female graduate student, Australia	"Personally, [it was valuable] just to be exposed to how [the Conference of the Parties] works, you know, to go in." —Female graduate student, Australia "Science's role can't be understated. It's the very bedrock upon which [the Conference of the Parties] need[s] to operate so that they were all working from, you know, a shared set of facts. So I think the role of discussing, you know, mitigation and adaptation science outside of the main negotiations is really important." —Female graduate student, Australia "Just having that at a personal level experience, it's something that you can apply in your professional life. And you're going to ask a professional to react different[ly] to these different stakes writing in the [Conference of the Parties]." —Female undergraduate student, Australia

issues faced by the planet—that negotiators discuss and students seek to address through action—affect everyone. The need for collaborative, virtual efforts has proved to be especially true considering the recent COVID-19 pandemic, which has left many students feeling alienated, anxious, and frustrated (Bowser et al. 2020). The time to act on climate change, promote students' desires to become climate advocates through their academic studies, and educate the next generation of leaders with an international and interdisciplinary understanding of climate policy is long overdue. The ongoing pandemic has reemphasized human interconnections on a global scale and the implications these connections have for potential future environmental challenges. Students have feelings of uncertainty, unease, and frustration about environmental policy actions on local to global scales but are determined to contribute to actions that are purpose-driven, equity-based, and impactful. To increase their effectiveness and impact in future careers, students will need to develop skills necessary to build and maintain complex collaborations across boundaries of country, discipline, and sector. Further, the need for youth who are scientifically and politically literate, willing and eager to participate, and able to advocate for future generations is evident. Other examples of collaborative, hands-on programs that have similar aims as YEAH include the SEEDS program of the Ecological Society of America (ESA; ESA 2021) and the future leaders fellowship program of the Aldo Leopold Foundation (Aldo Leopold Foundation 2021). Firsthand exposure to diverse perspectives on climate change impacts faced worldwide through these programs is likely to embolden students to act in their own chosen spheres of influence. Climate negotiations emphasize that the world is a network of interrelated people and places with problems that will only continue to grow without action. Strengthened skills and confidence in the shared realm of science, policy, and society will serve students well in future collaborations with other youth advocates and researchers of various

FIGURE 4.

A. Word Cloud of Learning Outcomes Pre-COP Experience

B. Word Cloud of Learning Outcomes Post-COP Experience

disciplines and during interactions with decision makers and community members. Ultimately, youth teams can play an important role in enhancing and achieving SDG 2030 and other future targets and in tackling the climate crisis using next-generation technology, international frameworks, and transboundary, equity-centered approaches.

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Gillian Bowser
Colorado State University, gbowser@colostate.edu

Sarah Whipple is a PhD candidate in ecology at Colorado State University. Her research focuses on changes in plant-pollinator interactions within western US protected areas using citizen science data, natural history collections, and technology tools. She is passionate about engaging students in their first-time field experiences in the national parks and international climate advocacy in UN climate negotiations. ORCiD:orcid.org/0000-0001-9280-1195

Shardul Tiwari is a PhD student in the Environmental and Energy Policy program at Michigan Technological University. His research focuses on energy justice, using social justice theories and conducting empirical studies to understand energy and climate policy formulation for high- and low-income countries. He also conducts research on meso-level policy analysis for international development organizations. ORCiD: orcid.org/0000-0002-3472-4547

Tashiana C. Osborne is a PhD candidate in climate sciences at Scripps Institution of Oceanography at the University of California–San Diego. Her research investigates western US precipitation events and their impacts. She pursues opportunities to invest in youths and support responsible environmental initiatives and decisions designed to tackle problems in the changing world in which we live. ORCiD: orcid.org/0000-0003-3279-4688

Gillian Bowser is an associate professor in the Department of Ecosystem Science and Sustainability at Colorado State University and a former American Association for the Advancement of Science (AAAS) Science and Diplomacy Fellow at the US Department of State in the Office of Environment and Science. Her research includes pollinators and ecological indicators as part of international environmental and climate policy. ORCiD: orcid.org/0000-0001-7994-2620

Sarah A. Green is a professor of chemistry at Michigan Technological University and a former Jefferson Science Fellow at the US Department of State. Her research interests include cycling of organic carbon in soils and aquatic systems, the impacts of climate change on the Great Lakes, climate communication, and international environmental and climate policy. ORCiD: orcid.org/0000-0002-8094-433X

Pamela H. Templer is a professor in the Department of Biology at Boston University, and her lab's research focuses on the impact of climate and air quality on biogeochemical cycling of carbon, water, nitrogen, and other elements in urban and rural forest ecosystems. She also works at the interface of science, policy, and community engagement, with the goal of coproducing knowledge and solutions that can help solve environmental challenges.

Susie S. Ho is the associate dean international for the Faculty of Science at Monash University in Australia. She also is the course director for the Master of Environment and Sustainability, which fosters interdisciplinary teaching and learning. She is passionate about designing and delivering innovative educational programs in science relevant to the changing world.

PRACTICE

A Model Interdisciplinary Collaboration to Engage and Mentor Underrepresented Minority Students in Lived Arctic and Climate Science Research Experiences

Arnell Garrett, *Delmarva Analysis*
Frances D. Carter-Johnson, *National Science Foundation*
Susan M. Natali, *Woodwell Climate Research Center*
John D. Schade, *Woodwell Climate Research Center*
Robert Max Holmes, *Woodwell Climate Research Center*

Abstract

The Polaris Project, a National Science Foundation–funded program at the Woodwell Climate Research Center, aims to comprehensively address minority participation in climate and Arctic science research. The project implemented design principles to recruit, motivate, and retain African Americans, Hispanics, Native Americans or Alaskan Natives, and women through immersive, field research experiences. The project included undergraduate and graduate students from environmental science, ecology, hydrology, biology, forestry, and geology. Ninety-five percent of participants identified as African American, Hispanic, Native American or Alaskan Native, and/or female. Critical participant outcomes included development of interdisciplinary research projects, involvement in self-efficacy and advocacy experiences, and increased awareness and discussion of Arctic research careers. All outcomes contributed to the Polaris Project's role as a model climate science research program.

Keywords: *Arctic science, immersive field research, interdisciplinarity, minority students, self-efficacy, underrepresented students*

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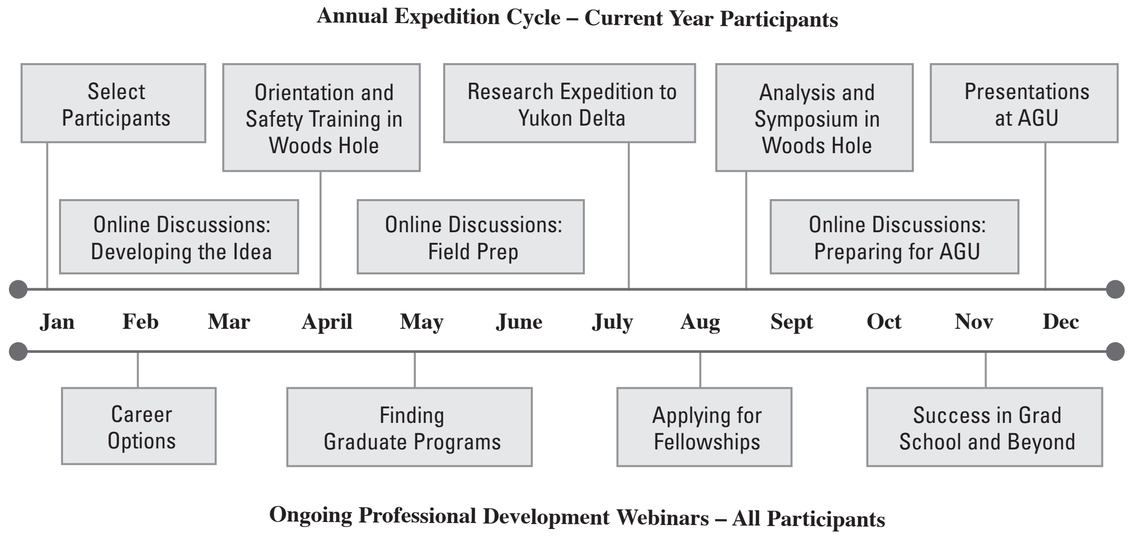
International, national, state, and local communities are facing increases in hazardous natural events due to climate changes. Responding to these events requires increased knowledge, innovation, collaboration, advocacy, activism, and an overall increase in participation in climate change research to effectively combat this global problem. This study focuses on the Polaris Project, a National Science Foundation–funded program that examines climate change in the Arctic. The Arctic is considered the epicenter of global climate change as evidenced by greater warming and the region's particular sensitivity to and influence on climate warming (Pastick at al. 2015; Saito et al. 2013). Despite the importance of understanding the perils of Arctic warming and climate change for human existence, research shows that the United States currently has a population of undergraduate and noncollege-educated citizens that is largely illiterate in the geosciences. This situation limits public understanding of Arctic research findings and global climate implications (Huntoon and Lane 2007; Peppoloni and Di Capua 2016). The lack of understanding is further evidenced by the fact that the field of geosciences has consistently awarded the fewest degrees for STEM disciplines across all academic levels (Callahan et al. 2017; Huntoon and Lane 2007; McDaris et al. 2017; Sherman-Morris and McNeal 2016; Wolfe and Riggs 2017). Huntoon and Lane posit that interdisciplinary and cultural diversification of students matriculating into Arctic and climate change graduate studies could improve the ability of the geosciences to communicate information across diverse populations.

To implement a comprehensive solution to the problem of lack of interest and illiteracy in the geosciences among diverse undergraduate STEM majors, researchers at the Woodwell Climate Research Center redesigned

FIGURE 1. Polaris Project Multiyear Plan for Cohort-Based Extended Research Experience



the Polaris Project in 2016. The budget, logistics, and recruitment-driven redesign focused on moving the field research experience from Siberia to Alaska to allow recruitment of undergraduate and graduate students from underrepresented groups who might be more open to a domestic research location (Garrett and Carter-Johnson 2019). The Polaris Project was designed to catalyze a change in the racial and ethnic demographics of Arctic science by engaging diverse students and faculty in cutting-edge Arctic research and providing extended research and mentoring opportunities to support the pursuit of Arctic studies. The project also aimed to increase racial and ethnic diversity among Arctic researchers within the US geoscientific workforce through interdisciplinary research collaborations between student researchers and faculty focused on climate change research. This article presents the Polaris Project as an innovative model of research participation designed to engage diverse communities. Polaris participants were encouraged to develop interdisciplinary climate change solutions based on their lived experiences with hopes of increasing their understanding of and participation in combating climate change.

Polaris Project Overview

To address concerns of underrepresentation in climate change research broadly and Arctic science more specifically, Polaris principal investigators (PIs) developed the Polaris Project, a cohort-based extended research experience. As outlined in Figure 1, an annual research expedition to the Yukon Kuskokwim Delta (YKD), Alaska, was the centerpiece of the experience. Additionally, the Polaris Project included in-person and virtual professional development opportunities such as virtual research team meetings and group attendance at the American Geophysical Union (AGU), the annual international conference for geoscience. These activities were aimed at (1) building research experiences and community for each cohort of Polaris participants and (2) providing students from underrepresented groups with the support needed to maintain interest and inclusion in climate change research fields. The following section provides details about the intent and implementation of the Polaris Project design principles.

Design Principle 1 (DP1): Recruiting and Retaining Diverse Participants and Building Capacity for Effective and Extended Mentoring

Recruiting diverse participants was built into the communication and application aspects of the Polaris Project. As shown in Table 1, the program announced the opportunity at historically Black colleges and universities; tribal colleges and universities and Native American–serving institutions; Hispanic-serving institutions; to science diversity groups; and to program officers of federal programs mandated with increasing diversity in STEM and the geosciences. Applicants to the program completed personal statements and obtained letters of recommendation, which described the following: (1) applicants' abilities to work well in a diverse group, (2) applicants' abilities to conduct remote field research, (3) applicants' abilities to maintain commitment when faced with challenges, (4) applicants' abilities to develop team working skills, and (5) applicants' interest in graduate-level studies in Arctic science–related disciplines. Using similar outreach techniques, Polaris PIs formed relationships with faculty at minority-serving institutions and recruited visiting faculty to serve as mentors in the Polaris Project.

Upon solidifying the cohort of students and visiting faculty mentors, the Polaris PIs hosted orientation at the

TABLE 1. Polaris Project Recruitment Emails by Institution Type and Program Year

Institution type	Program year		
	2017	2018	% of Average
Historically Black college or university	14	17	34%
Native American-serving institutions	13	9	24%
Other type of college or university	8	7	16%
Science Diversity Groups—unaffiliated with a college or university	4	5	10%
NSF Diversity Program directors	7	1	9%
Hispanic-serving institutions	3	3	7%
Total	49	42	100%

Woodwell Climate Research Center each April. Participants met mentors and other members of the cohort, learned about Arctic safety for the field research expectation, and discussed requirements for American Geophysical Union presentations. Participants also toured the Woodwell Climate Research Center, visited the center's research laboratories, received training for analytic instruments, practiced installing tents, and practiced safety exercises. Mentors and students engaged in research discussions at orientation and virtually via monthly online meetings about assigned and self-identified journal articles and participated in field expeditions to increase exposure to current permafrost research. The goals for these activities were to educate participants about how all STEM disciplines relate to permafrost and climate change and to stimulate their thinking about independent research questions.

The mentoring component of DP1 focused on building capacity for effective and extended mentoring. This component derived its foundation in the research mentoring literature as well as from the expertise of the PIs who designed and conducted research experiences. Research suggests that undergraduate student–faculty mentoring relationships often involve and are facilitated by graduate students and postdoctoral students (Atkins 2020; Joshi, Aikens, and Dolan 2019; Nicholson et al. 2017). Mentoring by several mentors that extends beyond a summer or academic year research experience also is recommended (Bradley et al. 2017; National Academies of Sciences, Engineering, and Medicine 2020; Nicholson et al. 2017). Polaris participants were offered a multiyear and multi-mentor research experience opportunity. However, this article only reports on mentoring that occurred in year 1.

Arctic scientists from varied backgrounds served as mentors for student participants. Mentors' research foci included studies of vegetation, aquatic ecosystems, greenhouse gases and permafrost thaw, and wildfires. The wide range of mentor expertise was critical for two reasons. First, given the complexity involved in investigating ancient carbon storage in the permafrost, multidisciplinary perspectives were needed. Second, participants received mentoring from scientists with interdisciplinary research experience, which enhanced understanding of the implications of permafrost thaw in this region for local and global climate systems. More details about the activities of the interdisciplinary research program are discussed in the next section, "Design Principle 2."

Mentoring in the Polaris Project was primarily conducted as group mentoring, allowing groups of mentors to respond to the research-related questions posed by participants. Polaris PIs served as faculty mentors for each Polaris cohort. At least one mentor from an underrepresented group also was included on the Polaris Project team each year. Although the Polaris faculty mentors remained consistent across cohorts, visiting faculty changed with each cohort but remained connected to the year's cohort of students for the entire year, from orientation to presentation at AGU.

Previous mentoring experiences of Polaris PIs indicated the need to build collaborative teams with both undergraduate and graduate students around specific research projects. Because the interdisciplinary nature of climate science allows pursuit of Arctic science graduate education as well as research and career opportunities for those with various undergraduate science degrees, graduate students both benefited as early career scientists and contributed to mentoring undergraduates through the collaborative research teams. Polaris Project graduate student participants, like the undergraduate participants, lacked previous participation in an interdisciplinary field experience in Alaska. Their research experiences with Polaris provided an immersive field experience, practice with writing analyses, and extended mentoring opportunities.

Design Principle 2 (DP2): Providing an Immersive and Interdisciplinary Field-Based Research Experience

Although recruiting and retaining diverse scholars and mentors was important to the Polaris Project, advancing scientific knowledge in climate science also was paramount. As such, the immersive and interdisciplinary field research–based experience, the centerpiece of the Polaris Project, often overlapped with or was the backdrop for the intentional recruitment and extended mentoring efforts. Polaris PIs identified, from previous Polaris expeditions, that the greatest impact on the team and the best research outcomes occurred when students and mentors explored new areas together. This novel exploration allowed both students and faculty to share in and benefit from the excitement of exploring a new and relatively understudied environment. As part of their exploration experiences, students learned how to read a landscape and identify geographic patterns by modeling the research activities of their faculty mentors. Additionally, the PIs found that students benefited most intellectually and produced the best research outcomes when they were allowed to take ownership of a research idea. A central tenet of the expedition, facilitated by the online scientific sessions and the orientation research article review, was for students to develop an independent research–based project. Polaris participants were guided to develop research projects with a focus on their disciplines as well as their scientific and cultural interests. Although Polaris PIs discussed technical needs and climate change implications of the student-developed projects with participants, the objective was to allow previous scientific and cultural experiences guide participants' research projects. The goal was for deep intellectual immersion into a scientifically and socially urgent topic that would resonate with students, build their awareness and exposure to interdisciplinary thinking, and instill a sense of accomplishment with climate change research. As another objective, the Polaris Project aimed to motivate and sustain participation in climate or Arctic science research careers. In summary, the Polaris Project considered the student-developed research projects as central to advancing scientific knowledge in climate science and preparing students for careers in climate or Arctic science. The following section outlines other aspects of the research and field experience design that make the comprehensive Polaris Project a vital model for climate change research and advocacy.

Literature on diversity in climate change research suggests cultural immersion in and consideration of marginalized cultures as opposed to assimilation into traditional research. Opportunities to facilitate forums for underrepresented minority researchers and students to share their perspectives on science and culture during traditional research activities are critical to increasing inclusivity in geoscience education (Adetunji et al. 2012; Callahan et al. 2015, 2017; Mattheis, Murphy, and Marin-Spiotta 2019). The Polaris Project intentionally allotted time for both mentors and mentees to share scientific and cultural thoughts and experiences during orientation and travel together to the expedition site and allowed the cohort to bond and build relationships outside of science. Prior to the field experience, mentors and mentees participated in climate change meetings with Alaskan Native community members, provided briefs on anticipated research questions, and received feedback on their research questions and ideas.

The immersive field experience was designed to provide an intellectually, culturally, and physically stimulating experience for student participants. Participants flew via float plane to the YKD camp, where they resided and collected data for 14 days. The isolated camp was located on the tundra, a semipermanent landmass consisting of rivers, ponds, and a complicated network of wetlands, abundant vegetation, and wildlife.

A major impact of climate change in Alaska, the YKD, and other regions of the Arctic is the melting of permafrost, the frozen layer beneath the tundra. Melting of the permafrost is critical to climate change because of uncertainties associated with the amount of carbon released into the atmosphere. These uncertainties result from limited information on the size and vulnerability of Arctic carbon pools. To investigate these uncertainties, Polaris Project participants from different disciplines designed student-developed research projects as part of the immersive field experience. Polaris PIs and participants worked on collaborative research teams to make fundamental scientific discoveries related to the vulnerability of permafrost carbon in the Yukon River Delta.

During the expedition, membership in collaborative research groups changed daily. Program participants were paired with different mentors and two to three different students daily to collect the data necessary to answer their student-developed research questions. This pairing exposed students to differing strategies for data collection in climate change research. Collaborative teams were expected to support data collection of each team member by collecting water samples, soil samples, and leaf or plant samples for three respective participants. On the following day, these three participants would be assembled into a different group with a different mentor. Participants were not exclusively paired with an individual mentor and were encouraged to find time to work with all available mentors to learn diverse research techniques that could be used to answer their research questions. However, based on student interests, each faculty member oversaw the research of specific students. This collaborative data collection approach facilitated interdisciplinary research for participants and mentors. All participants were allowed opportunities to discuss and understand research projects from different disciplines by supporting fellow participants in their projects.

After returning from the YKD, students analyzed their data at the Woodwell Climate Research Center for 14 days. During these two weeks, group mentoring continued to be driven by research questions and analytic techniques. Polaris PIs and visiting faculty were available for the post-expedition analysis time frame to guide the manipulation of data collected from the field, data cleaning, and data analyses. Students presented preliminary posters to the Woodwell and Woods Hole research community and continued to analyze data in preparation for poster presentations at the AGU conference in December.

Educational Theory and Assessment

Self-efficacious experiences or involvements that communicate to individuals their ability to organize and execute courses of action necessary to be successful in a particular vocation are thought to increase a person's interest in said career (Bandura 1986; Lent et al. 2008; Wu 2018). Self-efficacy, a domain-specific construct, has been explored to understand whether and how it increases during various occurrences such as classroom and research experiences. Research on self-efficacy has established that the strongest relationships between self-efficacy and positive outcomes emerge when specific forms of self-efficacy are matched with specific outcomes (Choi 2005; Pajares and Miller 1995). In other words, it is important to examine self-efficacy for specific involvements with relevant outcomes for those involvements and not general self-efficacy. This study explored the specific construct of Arctic scientific self-efficacy, or self-efficacy associated with conducting Arctic and climate science research.

Numerous studies report positive relationships between scientific self-efficacy and positive outcomes such as persistence in STEM fields (Britner 2002; Britner and Pajares 2001, 2006; Lent et al. 2008) and aspirations for or participation in graduate research experiences and careers (Adedokun, Bessenbacher, et al. 2013; Adedokun, Zhang, et al. 2012; Livinti, Gunnesch-Luca, and Iliescu, 2021). Although self-efficacy–related analyses are widely found for traditional research experiences and in fields less interdisciplinary in nature, few studies have considered immersive research and field experiences in the geosciences (Dykas and Valentino 2016; Kortz, Cardace, and Savage 2020; Pfeifer et al. 2021; Streule and Craig 2016; Trott et al. 2020). This study aimed to explore the application of self-efficacy–building experiences in the immersive field excursion associated with the Polaris Project.

Studies exploring the processes and contextual and participant factors associated with the positive relationship between scientific self-efficacy and research participation suggest that research skills are mediated through self-efficacy beliefs (Adedokun, Bessenbacher, et al. 2013; Adedokun, Zhang, et al. 2012; Berkes 2007). Berkes argued that research efficacy beliefs were derived from mastery experiences, one of four types of involvement often associated with increases in self-efficacy. Three other involvements (vicarious experiences, verbal persuasions, and emotional/physiological states) are thought to combine with mastery experiences to generate self-efficacy increases. However, mastery experiences are thought to have the greatest impact on self-efficacy (Bandura 1997). For this reason, this study focused on mastery experiences only. In the following section, mastery experiences are defined, followed by a brief overview of how mastery experiences interact and the justification for exploring them in this analysis of the Polaris Project.

Mastery experiences, most often based on previous encounters and execution of specific tasks, are defined when one successfully completes interesting, thought-provoking, and challenging vocation-related tasks that include well-planned activities that control for unproductive negative emotional and physiological arousals (Bandura 1997; Carter 2011). Research suggests that mastery experience tasks should be completed over an extended period with experts modeling the appropriate behaviors necessary to complete the task (Bandura 1997). Recipients of mastery experiences should receive instruction to guide individual performance and joint performance with experts to reinforce a sense of personal efficacy (Carter 2011).

With the goal of understanding the influence of self-efficacy on career aspirations in the face of limited understanding of the construct in relation to immersive, geoscience field research–based experiences, the 2016 Polaris PIs examined the presence of self-efficacy–building experiences in the Polaris program. Additionally, the study aimed to provide insight into any increases in awareness and understanding of Arctic career options potentially associated with self-efficacy–building experiences.

The interdisciplinary nature of Arctic science research, the Polaris Project's design and purpose, and the immersive and collaborative research expedition presented a culturally and scientifically complex assessment scenario. Assessment scenarios involving multiple participant groups and outcomes and limited explanatory mechanisms suggest the need for mixed-methods and participatory assessment approaches. The mixed-methods and participatory assessment approach was implemented in several steps. First, the assessment team included two researchers of color with expertise in behavioral and educational disciplines and experience identifying and assessing self-efficacy in undergraduate research settings to explain the benefits of research participation of underrepresented minorities in STEM. These researchers embodied lived experiences

TABLE 2. Polaris Outcomes of Interest with Relevant Interview Questions

Polaris outcomes of interest	Interview question
Career goals	Please describe your 5-year and 10-year educational and/or career plans. Probe: What are your thoughts on becoming an Arctic scientist?
Mastery experience: interesting	What is the most interesting thing you did during your summer research experience?
Mastery experience: challenging	Please describe your most challenging experience as a Polaris participant and how you dealt with it.
Verbal or social persuasion	What type of feedback have you gotten on your fieldwork, data analysis, or research project? What type of feedback have you gotten from professors, peers, and family as a result of the Polaris Project?
Vicarious experience	Can you describe any Arctic researcher's work that you admire the most? Do you consider that person a role model? Are there any Arctic researchers that you consider a role model? How do you think you are similar to that person?
Physiological state	Tell me about your emotional state during various parts of the project.

by participating in and studying research experiences in STEM as diverse scientists who had ties to minority-serving institutions. Second, prior to the immersive field experience, the evaluation team participated in the Polaris Project Spring Orientation and online sessions with students to understand and observe implementation of the design principles. Third, program participants were regularly encouraged to develop their own research projects, hypotheses, and designs and to use mentors to support completion of their projects. Faculty also were encouraged to (1) support the detailed technical needs of their students' projects; (2) guide participants to consider the broader implications of Arctic science; and (3) explore linkages between their scientific major or area of focus and Arctic science. This approach resulted in a partnership among the researchers, the PIs, and the participants to inform and collect rich data about the meaning of the participant's experiences.

In year 1 of the program, the PIs did not receive training on how to build mastery experiences. However, the program was assessed for self-efficacy traits. The year 1 assessment reports included detailed information on the components of mastery and other self-efficacy experiences. The program was modified to intentionally incorporate those experiences in year 2 of the program.

This study was limited to the participants' involvement in one cohort-based extended research experience. Although students were offered multiyear interactions, the qualitative data analyzed and reported in this article assesses only experiences that occurred in the first year of participation. Analyses of the qualitative participant interview data represented the first component of the mixed-methods research process. Although a longitudinal survey is planned to collect quantitative data from all undergraduate and graduate participants, generalization of the findings will be limited given that each cohort includes only 12 undergraduate and graduate students. The potential for robust quantitative analysis from the Polaris Project is limited. These limitations further justify the focus on qualitative data to assess the Polaris program and to examine the processes of research experiences, the benefits of those processes, and their influence on students' career aspirations.

Methodology

To assess the presence of self-efficacy–building experiences and explore the potential influence of those experiences on participants' self-efficacy and career goals, a mixed-methods, participatory assessment approach was implemented in several steps. The evaluation study with relevant data collection instruments was approved by the Massachusetts General Hospital Institutional Review Board. The relevant data collection instruments were interview protocols for interviews utilized during orientation (baseline interviews), during the research expedition (midpoint interviews), and at the American Geophysical Union Fall Meeting where participants' research posters were presented (end of year 1 interviews). The baseline, midpoint, and endpoint interview protocols were developed by the assessment team. Self-efficacy prompts included in the interview protocols are listed in the interview questions in Table 2. The interview questions followed standard procedures for self-efficacy research by asking about respondents' confidence or experiences associated with completing a given task.

For each cohort, interviews were conducted as planned, at orientation (baseline), during the research expedition and data analysis camp (midpoint), and during the American Geophysical Union Fall Meeting (endpoint). Interviews were conducted for the 2017, 2018, and 2019 Polaris project cohorts. However, this article only reports results from the 2017 and 2018 cohorts.

Data Analysis

The data were evaluated qualitatively by members of the Polaris Project assessment team. Interviews were transcribed in Trint, an online transcription software. Nvivo, a qualitative software package, was used to analyze the data. Responses were coded first by question, grouped by response types, labeled, and then analyzed both quantitatively and qualitatively. For example, reasons for choosing a STEM major were coded as "reason for major." The responses were then grouped by comments that indicated "enjoyment" and "other." Keywords from the definitions and question prompts associated with the four types of involvement that result in increases in self-efficacy were used to code participants' responses. For mastery experiences, a participant's response was coded as a mastery experience if the respondent described the involvement as both interesting and challenging. Because previous studies classify completing a research poster as a mastery experience, respondents' descriptions of completion of a research poster were considered a mastery experience, and the analyses examined what respondents associated with those experiences.

Word clouds were chosen to illustrate self-efficacy–building experiences from the language respondents used to describe aspects of the Polaris Project and to characterize whether language suggested the presence of self-efficacy–building experiences. Different word clouds of participant language from midpoint and endpoint interviews were developed to illustrate language and emerging themes for the field experience and data analysis camp and the poster presentation, respectively.

In the process of analyzing the language of Polaris participants, it was hypothesized that the design and structure of the Polaris Project allowed for participants to have self-efficacy–building experiences and to increase awareness and understanding of Arctic career options. Similarly, by exposure to various aspects of Arctic research, it is anticipated that Polaris participants will serve as climate change advocates with broad public audiences; however, this has yet to be explored in assessment of the program's outcomes.

Although this study did not explore the influence of group mentoring on participants' experiences, it was thought that the interdisciplinary demands of climate change research would negatively interact with the benefits of an individual mentor for Polaris participants. The question remains: As participants did not have an individual mentor in Polaris, did they feel lost or disconnected? Interview questions did not address this aspect of participants' experiences. However, the longitudinal survey and future Polaris projects should consider incorporating items to better assess this aspect of the Polaris Project. Two potential questions may include the following: (1) What are the impacts of having several mentors for mentees as they participate in the Polaris Project? (2) What is the implication of having multiple mentors for future career prospects in Arctic science research? Planned future analyses of the Polaris Project will examine data for all three cohorts as well as explore the benefits of the extended mentoring relationship. The Polaris program can be more attentive to mentoring by providing mentors training on the following: (1) building self-efficacy in trainees; (2) valuing culture in research experiences; and (3) promoting intersectionality in geoscience research, which will increase understanding and benefits from the extended mentoring relationships.

Demographics and Academic Disciplines

Table 3 illustrates that the Polaris Project included students of multiple racial and ethnic groups, academic levels, and climate science academic disciplines. Gender and racial/ethnic groups, including Native Americans, Hispanics, and African Americans, who have traditionally been underrepresented in Arctic science research represented over 50 percent of Polaris participants. Moreover, 75 percent of Polaris participants identified as female. Polaris participants spanned all levels of higher education from first-year undergraduates to graduate students. Both the 2017 and 2018 cohorts consisted mostly of upper-level undergraduate students, with fourth-year students representing one-third of the participants. Although third-year students composed 50 percent of the cohort in 2017, participants were spread across all academic levels in 2018. In terms of academic discipline, the 2017 cohort featured participants mostly from biology (33 percent) and hydrology (25 percent), whereas the 2018 cohort was made up mostly of environmental science (58 percent) and ecology (17 percent) majors. In each cohort of students, the majority reported aspirations to obtain an advanced degree in STEM during baseline interviews.

Self-Efficacy Experiences and Outcomes

The Polaris Project upholds the goal of providing inclusive experiences for both undergraduate and graduate students. Therefore, to maintain anonymity of the participants, the results are aggregated and do not distinguish between undergraduate and graduate students. Themes and language emerging from the student interview data suggest that components of the Polaris Project align with activities that provide mastery experiences. All Polaris participants expressed interest in their activities, challenges, stress, and personal success for the three major components of the Polaris Project: the field experience, the data analysis camp, and the poster presentation. All participants described the major components as interesting or fun but also reported stressful experiences during fieldwork. Likewise, although most participants reported that the data analysis period was stressful, some participants enjoyed it. To convey the language used by participants to describe the interesting and challenging aspects of the field experience and data analysis camp, midpoint interviews for 2017 and 2018 were combined into a word cloud shown in Figure 2. The most frequently used words appear the

TABLE 3. Descriptive Statistics of Polaris Participants for 2017 and 2018

Demographics	2017 (n = 12)	2018 (n = 12)
Gender		
Male	25%	25%
Female	75%	75%
Race/ethnicity		
White	42%	34%
Underrepresented minorities	58%	66%
Native American	25%	25%
Hispanic	25%	17%
Asian	8%	8%
African American	0%	8%
Other/Multiracial	0%	8%
Classification		
First-year undergraduate	0%	8%
Second-year undergraduate	0%	17%
Third-year undergraduate	50%	18%
Fourth-year undergraduate	33%	33%
Master's student	0%	16%
PhD student	17%	8%
Major		
Biology	33%	9%
Ecology	0%	17%
Education	0%	8%
Environmental science[a]	17%	58%
Forestry	8%	0%
Geology	8%	0%
Hydrology	25%	8%
Natural science	9%	0%
Academic goals		
PhD	75%	50%
Unknown	8%	25%
Master's	9%	17%
Bachelor	0%	8%
MD	8%	0%

Note: [a]Includes global environmental change and Earth and planetary sciences

largest in the cloud and included words such as *amazed*, *great*, *excited*, and *pretty*. Other frequently used words appearing in the cloud included words such as *people*, *field*, *experience*, *project*, and *done*. Words that related to challenging experiences included *worry*, *crazy*, and *hard* and appear in smaller type because they were mentioned less frequently.

FIGURE 2. Word Cloud of Participant Field and Data Camp Language for 2017 and 2018: Midpoint Interviews

FIGURE 3. Word Cloud of Participant Field and Data Camp Language for 2017 and 2018: Endpoint Interviews

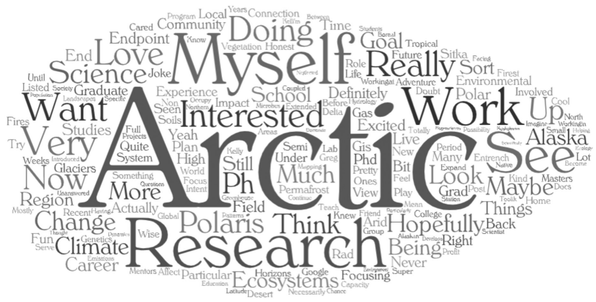
Figure 3 illustrates the language participants used to describe the poster presentation component of their Polaris experiences in endpoint interviews in 2017 and 2018. Although some participants reported stress during the preparation phase, all participants described enjoying presenting the posters. As described, mastery experiences involve the execution of specific tasks that may be described as interesting, thought provoking, and challenging. Words such as *stress*, *interested*, and *think* were prominently used by participants to describe the poster presentation process, suggesting that this activity aligned with mastery experiences.

Arctic Career Awareness

As mentioned earlier, a broader objective of the Polaris Project is to motivate and sustain participation in climate or Arctic science research careers. To this end, data were collected about participants' experiences with the field expedition, their experiences analyzing and presenting data, and their awareness of and aspiration for Arctic careers. Participants were classified as having Arctic/climate science career goals if the words *Arctic*, *climate*, or

FIGURE 4. Word Cloud of Participants' Career Goal Responses for 2017 and 2018: Baseline

FIGURE 5. Word Cloud of Participants' Career Goal Responses for 2017 and 2018: Endpoint



Alaska emerged when they were asked about their career goals. Participants were classified as having non-Arctic/climate career goals if they articulated a career goal but did not mention the words *Arctic*, *climate*, *Alaska*, or any words pertaining to Arctic science. Lastly, participants were classified as undecided if their responses excluded words related to Arctic science and included the words, *I don't know*, *anywhere*, or *not sure*.

The percent of participants using language about Arctic careers more than doubled in 2017, from 25 percent at baseline to 73 percent at endpoint, and in 2018, from 33 percent at baseline to 70 percent at endpoint. The word cloud in Figure 4 shows an overall increase in the use of language about Arctic science careers across all students. Comparing Figure 4 (baseline) to Figure 5 (endpoint), it is seen that the word *Arctic* is more prominent, indicating more frequent mention at endpoint than baseline, when *Arctic* is present but smaller. This suggests an increased awareness and understanding of Arctic career options.

Challenges and Lessons Learned

The Polaris Project overcame challenges associated with immersive and remote field research–based experiences such as addressing logistical arrangements, personal health needs, and interpersonal conflicts. The principal investigators and project staff attempted to address these challenges by building relationships and collaborations on personal and professional levels before the remote experience as well as having appropriately trained medical staff and equipment on site.

Regarding research experiences, challenges were identified with conducting fieldwork, traveling, and delivering a research product in the summer. From a self-efficacy standpoint, mastering these challenging experiences may be considered opportunities for participant growth. However, strategies to balance stress and growth are necessary when designing intense and immersive experiences for future programs. Presenting experiences theorized to have an impact on interest in climate change careers in participants in an Arctic science undergraduate research program resulted in an effective interdisciplinary model for teaching about climate change impacts that allowed for self-efficacy–building experiences, increased awareness among participants about climate change research careers, and participation in climate change advocacy.

The impact on climate and Arctic science facilitated by the Polaris Project is successful because it allows students to apply their scientific interests and cultural experiences toward solving a research problem. The model allows for interdisciplinary experiences that provide broad knowledge of climate change research and its impacts. Because of the diverse representation of participants, application and knowledge transfer to others in communities currently underrepresented in climate change research, work, and advocacy are anticipated. Disseminating knowledge to underrepresented communities will allow for far-reaching approaches to combat the harmful impacts of climate change. Programs interested in providing self-efficacy–building experiences and increasing awareness of climate change research and careers should consider deeply immersing students in intellectually and physically challenging environments to address scientifically and socially urgent topics. This immersion is critical to stimulation and widespread implementation of the diverse, innovative, and impactful climate change solutions necessary to change the current course of the planet.

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Frances D. Carter-Johnson
National Science Foundation, frajohns@nsf.gov

Arnell Garrett—an independent policy researcher, evaluator, and founder of Delmarva Analysis, LLC—earned a BA from the University of North Carolina at Chapel Hill and an MPP from the University of Maryland, Baltimore County, and has conducted analyses for leading nonprofit and professional society organizations such as AARP and the American Institute of Physics.

Frances D. Carter-Johnson is an education data scientist in the Directorate for Education and Human Resources, Division of Human Resource Development, at the National Science Foundation, where she is responsible for assessing outcomes of broadening participation programs and contributing to the body of STEM education policy research and knowledge.

Susan M. Natali is an associate scientist at the Woodwell Climate Research Center, where her research focuses on the impact of climate change on terrestrial ecosystems, primarily on arctic permafrost.

The late John D. Schade served as a program officer in the Division of Environmental Biology at the National Science Foundation (NSF), where he managed the Ecosystem Science and Long-Term Ecological Research programs. Before his time at NSF, he spent a sabbatical year at the Woodwell Climate Research Center and 10 years on the faculty at St. Olaf College.

Robert Max Holmes is a senior scientist and deputy director at the Woodwell Climate Research Center. Conducting field research throughout Siberia, Alaska, and the Canadian Arctic, he has contributed toward understanding how a changing climate will impact Arctic rivers, watersheds, and permafrost.

The Use of Model Intercomparison Projects in Engaging Undergraduates in Climate Change Research

Robert H. Nazarian
Fairfield University, rnazarian@fairfield.edu

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Computational models are essential in simulating the changing climate and the ramifications for ecological, economic, and social systems. To improve model performance and study climate change impacts across physical, biological, and social systems, model intercomparison projects (MIPs) are regularly conducted. Currently, the climate community is engaged in Coupled MIP Phase 6 (CMIP6), under which there are 23 active MIPs exploring specific aspects of the climate system (Eyring et al. 2016; WCRP 2019). CMIP6/MIPs are a massive undertaking, with contributions from more than 30 international groups and the subsequent analysis exploring fundamental physics as well as potential adaptation and mitigation strategies (Eyring et al. 2016; WCRP 2019).

Each model is first analyzed by its home agency, yet MIPs represent a crucial tool for undergraduate researchers to meaningfully contribute to climate change research. The MIP data are ideal for undergraduates since

1. they do not require students to run the model simulations themselves, which can be time-consuming and expensive with costs of approximately $1,000–$100,000 per simulation (Schär et al. 2020; Schulthess et al. 2019; Walker 2009);
2. they are publicly available;
3. they offer a breadth of research avenues based on student interest such as climate-induced migration of fish (Ruane et al. 2016), changes in meteorological patterns (Gerber and Manzini 2016), and changes in agricultural practices and land use (Ruane et al. 2016; Lawrence et al. 2016);
4. they offer expansive yet constrained scientific data, which provides structure for the students; and
5. they foster collaborative research between undergraduate researchers and the modeling centers producing/refining these models, as well as stakeholders working in climate advocacy, mitigation, and adaptation.

Furthermore, the number of MIPs has grown over time, leading to a vast repository of model simulations (CMIP6 will produce at least 20–40 petabytes of data) that have not been fully analyzed (WCRP 2019; Schär et al. 2020; Schulthess et al. 2019).

For these reasons, MIPs are an ideal tool to engage students in climate change research, and this research model has been adapted at Fairfield University. Students from various majors who are engaged in this research benefit from the computational nature of this work, which is immediately transferable to any career path upon graduation. Students are involved in all aspects of the research: posing the scientific questions, selecting the appropriate MIP/simulations to answer those questions, conducting the computational analysis, and presenting their results. All aspects of this process engage students in topics outside of the traditional undergraduate science curriculum (particularly at a liberal arts institution) while focusing on applications. Student researchers have primarily used a suite of simulations within CMIP6 that is representative of "business as usual" (Van Vuuren et al. 2011) greenhouse gas emissions and have been analyzing future climate projections. Although students may choose from a variety of scientific questions, one of their signature achievements is the analysis of extreme temperature and precipitation in a warming climate and the associated societal impacts, which is well outside their traditional physical sciences curriculum.

This path of undergraduate climate research has sparked cross-disciplinary discussions at the institutional and local levels, as this vein of research allows students in the physical sciences to participate in larger discussions on climate change. Students conducting this research participated in an interdisciplinary climate session at Fairfield's annual research symposium, and the hope is that this interdisciplinary session will become a yearly tradition to engage students across disciplines. This research has also led to a broader cooperation with nonprofit and local groups, collaborations with stakeholders in the private sector, and consultation with scientists at R1 institutions.

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Developing Multiple Literacies and Foundational Research Skills in Students through Audio Narratives on Global Warming Solutions

Laura Guertin, Annie Jansen, and James Berkey
Penn State Brandywine, guertin@psu.edu

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Introductory-level Earth science courses provide students with an important opportunity to build foundational skills for research and communication of science content, especially when it comes to climate science. The introductory course at Penn State Brandywine "Earth in the Future: Predicting Climate Change and Its Impacts Over the Next Century" utilizes a scaffolded instructional approach and faculty from several campus units to develop multiple literacies (information, digital, science) and professional skills (writing and speaking) in students. Enrolling 20 students in each course section each semester (number of sections offered varies per semester), the course highlights not just the climate challenges facing society but also promotes an awareness of climate solutions to reverse global warming such as those developed by Project Drawdown. Students initially select a Drawdown solution as their focus for the semester. The first step addresses information literacy, as students learn strategies to find climate sources and evaluate these sources for credibility and reliability. For the purposes of this assignment, students are encouraged to use sources intended to appeal to non-STEM audiences (*Scientific American, Ensia,* the *Washington Post*, etc.). By familiarizing students with these sources now, it is hoped that they will access them after graduation to continue learning content. The second scaffolded step prepares students to write a story in the format of a script they can record. The campus writing center assists students with templates (for this course, the COMPASS Message Box was assigned) to frame the information for their story. The writing center also brings professional and peer tutors to the classroom to facilitate group peer review of the first draft of the script. The final scaffolded step involves digital training with audio recording software and hardware freely available on campus. Audio was selected, as it is an accessible technology with a low barrier to entry, offers an ease of recording off campus, and provides the ability to listen and review during commuting times.

This audio narrative assignment has provided additional outcomes beyond improved knowledge in climate science. Students now seek assistance from librarians for projects in additional courses—there is a "barrier" that has been broken down, and students realize numerous resources are available. Students also utilize the campus writing center for assistance beyond this course, having learned how to book appointments, and meet with a tutor to complete their Message Box. Students acknowledge that there is value in having a peer review their work. Finally, students report a sense of accomplishment and pride once the audio file has been completed. Some students include the audio file on their LinkedIn profile and in ePortfolios. Developing students' scientific literacy, especially about climate change; increasing their familiarity with campus resources; and building their confidence in communicating scientific content establishes an important foundation in the early undergraduate years and can lay the groundwork for successful third- or fourth-year research experiences.

Researching Global Climate Change Challenges to Solve Local Issues with Undergraduate Research and Physical Models

Tara S. Kulkarni
Norwich University, tkulkarn@norwich.edu

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Experiential education, community engagement, and service—the core of Norwich University's 200-year-old mission—are increasingly driven by emerging needs and research. However, the role played by human beings in the meteoric impacts of a changing climate are often controversial subjects on college campuses. Shealy and colleagues (2017) found through a nationwide survey that more than half of the students enrolled in a civil engineering program do not believe in anthropogenic climate change and are less likely to want to address climate change in their careers. As the first private university in the United States to offer the civil engineering major and as the birthplace of ROTC, Norwich University has produced generations of leaders and builders of the nation's infrastructure, including senior military leaders at the forefront of fighting climate change to ensure national security. It is imperative that all graduates—especially engineers—are trained to understand climate change and build for resilience and long-term sustainability.

From 2012 through 2020, students in an introductory environmental engineering course have used a service-learning project to research climate resilience challenges and solutions. Issues of local significance exacerbated by climate change are connected to global concerns in three to four sessions of the three-hour laboratory portion of the course. The research is reported in briefs, reports, or conversational blogs. Students build physical models representing their understanding of the challenge or their engineering solution to address the problem. These models were disseminated in community education and outreach efforts, K–12 classrooms, community fairs, or STEM events such as the First Lego League Robotics competition.

Overall, 57 projects researched by almost 200 undergraduate students, involved approximately 30 community partners, and reached hundreds of grade schoolers and community members across Vermont. The undergraduate student reflections shifted from an initial reluctance at being "forced into this project" to deeper understanding of the challenges and solutions. They empathized with community partners, grew into their roles as leaders and team members as appropriate, and connected their professional training and education to engineer a transforming world. They also earned research fellowships and internships, and the classroom experience led to capstone projects and graduate school pathways. This scalable model can be easily adapted across institutions; meets multiple university objectives; and offers students a voice, agency, and an ability to take small meaningful actions in a big, complex, and global challenge.

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Simulating International Climate Negotiations in Classrooms

Thomas Hickmann
Utrecht University, The Netherlands, t.hickmann@uu.nl

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A key challenge of teaching climate change to undergraduate students is: How can the enormous breadth of the topic with its underlying root causes, mutual dependencies, and various existing political response strategies be transferred into the classroom in an engaging way? One fruitful option is to let students play and experience the complexity of global climate governance firsthand.

To this end, a simulation of the international climate negotiations was designed for more than 50 students of political science and other study programs dealing with sustainability. Based on the author's personal involvement as an observer of several Conferences of the Parties under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), this course was developed in close collaboration with didactic experts. At first, the time-consuming preparations and uncertainty about the format's suitability for larger classes seemed daunting. But a key advantage of such simulations is that they are highly adaptable to groups of different sizes, academic backgrounds, or learning levels and can be used to teach a number of major concepts within the same framework. Although many possibilities exist to adjust the framework to different learning goals, the primary objective of such simulations is that students grasp the difficulties to achieve collective action and prevent the overuse of common pool resources under conditions of anarchy and huge asymmetries in the global distribution of power and wealth.

The course is structured in three parts. In an introductory phase, students gain an overview of the scientific basis of climate change and become familiar with the adverse effects of global warming such as sea level rise, extreme weather events, and crop shortfalls that all affect most strongly the global South. Then, the game starts, and students adopt roles of the main players such as states, nongovernmental organizations, and the UNFCCC Secretariat. The actual simulation can be closely associated with the political realities and latest developments in international climate diplomacy but needs to be broken down into a certain number of feasible negotiation items. Students may carry out the simulation for a few hours, or the exercise can run for several sessions or for an academic term. After the simulation, students step out of their roles and reflect on their practical insights and different learning experiences before they critically discuss approaches that provide explanations for the complexity of global climate governance.

This course has three pedagogical highlights:

1. Students have the chance to make use of their conceptual knowledge by testing it out in application-oriented settings.
2. Students are encouraged to train and enhance their problem-solving competencies for their later professional work such as reading, oral and written communication skills, team and conflict management, as well as thinking and reasoning abilities.
3. Students come to know a new teaching method in a transparent manner that offers them the possibility to reflect on their individual working process and learning progress.

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OTHER FEATURE ARTICLE

Positioning Humanity before Progress: Students' and Mentors' Perceptions of the COVID-19 Impact on Undergraduate Research

Miloš Savić, Naga Rama Kothapalli, *University of Oklahoma*
Hayley C. Lanier, Erin K. Freeman, *University of Oklahoma*
Lisa Ratliff, Emma Hillermann, Courtney Martin, *University of Oklahoma*

Abstract

One of the most important actions in research and mentoring is to adjust expectations and provide emotional support when unexpected events occur. In this article, the authors investigate the impacts of COVID-19-based campus closures on undergraduate research and the student and faculty impressions of the adjustment. Through interviews with 28 students and 17 mentors from a campus-wide undergraduate research program, common themes in the responses to COVID-related impacts were found. Students had to adjust to the type or scope of their research obligations while handling academic responsibilities, and mentors explicitly considered students' well-being above expectations related to research. Providing professional development to mentors that emphasizes flexibility and compassion in the mentor-student relationship is recommended.

Keywords: *COVID-19, disaster, empathy, mentorship, undergraduate research*

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Similar to many higher education institutions worldwide (Grimm 2020), the University of Oklahoma (OU) closed nearly all activities in March 2020 due to the COVID-19 pandemic. One activity directly affected by this closure was undergraduate research, with the initial closure halting or shifting undergraduate research plans and the later reopening providing its own limitations due to restrictions on undergraduates' campus presence. As a result, both faculty and students were forced to change their usual research protocols and create alternative plans, often having to pivot from a face-to-face research mentoring relationship to one that existed solely through virtual interactions. Although previous research has suggested that virtual mentorship can provide some of the same benefits of face-to-face mentorship such as social and academic support as well as some other benefits not provided by face-to-face mentorship such as increased flexibility (Owen 2015), members of the mentoring relationship often need time and training to obtain these benefits (Ensher, Heun, and Blanchard 2003). Given the abrupt nature of COVID-19 campus shutdowns, neither faculty nor students had time to prepare for this switch to virtual mentoring, giving rise to several unforeseen challenges such as ways to continue a research program that relies on in-person data collection, interaction with on-campus research labs, and methods to handle differences in time zones and differential access to technology. Although common in community-wide disasters (Smith, Drefus, and Hersch 2011), these unexpected challenges to routine have been related to increased anxiety (Cénat et al. 2020), feelings of uncertainty (Smith, Drefus, and Hersch 2011), and decreased functioning (Zisberg et al. 2007) while providing those affected with opportunities to make innovative changes in an effort to meet goals (Magni et al. 2013).

In light of the many effects of these challenges, the authors were interested in how students and faculty mentors perceived the effects of COVID-19 on their undergraduate research programs, especially since previous research has demonstrated time and again that participation in undergraduate research can have incredibly positive effects for students (e.g., Kendricks et al. 2019). To this end, a series of qualitative interviews were conducted with participants of OU's Four-Year Research Engagement (FYRE) program in which the effects of these changes on undergraduate researchers were evaluated, the impacts of COVID-19 on supporting undergraduate research and undergraduate students were assessed, and the psychological implications of those impacts were discussed. The results suggest that COVID-19 necessitated innovative and humanistic adjustments by both mentors and students to ensure successful and continued collaboration. Particularly, the mentors made adjustments that are similar to best mentoring practices such as balancing rigorous expectations for research with emotional support and appropriate personal interest in students' well-being (Shanahan et al. 2015).

Background: FYRE Program

The NSF-funded FYRE program supports the intellectual and career development of undergraduate researchers. As the *de facto* campus-wide interdisciplinary STEM development program, FYRE matches students with faculty mentors to conduct cutting-edge research across 16 STEM departments at OU. With the goals of providing an immersive research experience and building a community of undergraduate researchers, the FYRE program serves approximately 80 students per year. Although undergraduate participants are primarily first-year students interested in research, the FYRE program also provides a tiered curricular opportunity to students to incorporate research and professional development with course-credits toward degree completion. As part of students' research participation, they are expected to devote 10–12 hours per week to research-related activities and present their work at the end-of-semester public poster presentation. To supplement those experiences and build community, students meet as a group for biweekly information sessions to discuss scientific ethics and science news as well as learn about various STEM careers (Kothapalli 2018).

After spring break of 2020, and with little notice, all non-COVID-19 research laboratories closed, and OU moved its entire instructional component online. The shift from in-person meeting about STEM careers to an online format was smooth, but the transition of the research component to distance interactions varied. During the transition, FYRE program administrators created guidelines for faculty mentors and provided students with a list of instructions for the remainder of their semester. There were numerous discussions about poster preparation and presentation (atypical for a regular semester) conducted via emails and Zoom sessions. Despite the curtailed semester, the poster session was still hosted virtually to allow the students to demonstrate their progress in their scientific understanding as well as the impact of their contributions. To show the breadth of the topics where the FYRE students were engaged in research, a sample of research areas and the titles of posters presented are shown in Table 1.

To examine the impact of COVID-19 shutdowns on student research, research participation was classified into six categories using student project descriptions (see Table 2). Five out of every six FYRE students shifted their research, conducted a literature review, did not have guidance, or did not complete a project. These effects of the COVID-19 shutdowns added to the authors' curiosity about the ways such a large disruption in undergraduate research were addressed by students and mentors.

Methods

To understand how faculty and students worked together to address disruptions caused by COVID-19, a series of semi-structured interviews with FYRE students and mentors were held. All recruitment, consent, and interview protocols were approved by OU's IRB process (#12003). These participants self-selected via an email sent out by the administrator (an author) that had a link to scheduling an interview. Three undergraduate students (all authors) interviewed 28 FYRE participants, all of whom were STEM students. There was an opportunity for students to identify gender and race/ethnicity during the interview: there were 14 women, 12 men, and two who did not state their gender; as well as 20 White/Caucasian students, four Asian students (Chinese, Indian, Taiwanese, Vietnamese), three Black students, and one Hispanic student. One faculty member (an author, not the FYRE administrator) interviewed 18 FYRE mentors from more than 10 disciplines in STEM (one chose to be interviewed but did not want to be recorded so was not included in the analysis). When asking for consent, all participants (both students and mentors) were asked for permission to directly quote them in any future publications or presentations and, immediately after, were asked to provide a pseudonym of their choice. Participants provided one, asked for their whole name or first name to be used, or asked the researchers to choose a name for them (e.g., Mentor A).

Both interviews used semi-structured interview protocols that included questions about COVID, with shifts in emphasis based upon the identity of the interviewee. For example, the student protocol started with the following question: "How has your participation in the FYRE program been impacted after COVID-19?" For mentors, the protocol was changed from "participation" to "role as a mentor." However, since the interview was semi-structured, the question prompted follow-up questions based upon the answers given by the participants.

Interviews were transcribed and initially coded into broad categories (one being COVID-19 impact) for a larger investigation. In vivo coding and theming analysis (Saldaña 2016) coupled with nVivo™ software were used to learn how COVID-19 affected FYRE participation, mentorship, and research for mentors and students. Five themes for mentors and seven themes for students emerged from the analysis, which is discussed below.

TABLE 1. Broad Areas of Research and Sample Poster Titles as Presented by FYRE Students in Spring 2020

Area of research	Sample poster title
Anthropology	Exploration of Sub-Saharan Trade Connections through Analysis of Ancient Glass from the Archaeological Site of Walalde
Biochemistry	Modification of M13 Phage with PIII Protein for Therapeutic Nanoparticle Development
Biology	The Secret of the Wings Morphology and Species Identity
Biomedical engineering	Jaw Movement Artifacts in fNIRS Signals Measured from the Auditory Cortex
Chemical engineering	Expanding ATRP for Acidic Phosphonate Monomer Synthesis
Chemistry	Carbene-Initiated Cascade Reactions for the Synthesis of Diverse Scaffolds
Computer science	Modeling the Evolution of Communication Using Artificial Neural Networks in Foraging Environments
Electrical engineering	Creating a Bird Phantom
Health and exercise sciences	Oral Contraceptives and Exercise-Induced Fatigability
Mathematics	An Exploration of Non-Euclidean Geometries
Mechanical engineering	Micro-Encapsulated Phase Change Material Within a Multi-Phase Flow Loop
Meteorology	Analysis of the Diurnal CO_2 Cycle and Its Daily Variations
Physics and astronomy	The Methods of Modeling White Dwarfs and the Importance of Their Continued Study
Plant biology	Drought Resistance of Switchgrass Genetically Engineered for Biofuels
Psychology	Evaluation of the Cognitive Effects of Iron Deficiency
STEM education	Schema-Based Instruction for Improving the Mathematical Problem-Solving Skills of a Rural Student with EBD

TABLE 2. Effects on FYRE Student Research Projects after COVID-19 Shutdown in Spring 2020

Effects on student projects	No. of students (n = 72)	Percentage of students
Switched to data analysis (self-collected)	8	11%
Switched to data analysis (previously collected)	17	23%
Conducted literature review	28	39%
Did not receive guidance	5	7%
Did not experience change in research activity	12	17%
Did not present	2	3%

Results

Impact on Mentors

Interview evidence indicates that, during this difficult time, mentors adapted their mentoring style and research expectations to prioritize students' personal well-being over research progress (see Table 3). This often meant regularly checking in with their FYRE students, as Mentor D stated: "Mostly making sure that they've got what they need just as people… that they're healthy, that they know that somebody cares about them, that they know that there is a faculty member who just wants to make sure everything's okay." This also involved lessening students' workload, especially if mentors discovered that the students faced difficulties in their personal lives. Mentor responses also showed that they attempted to create stability by holding regular research meetings and found that these meetings were a positive distraction for some of their students. In interviews, mentors most frequently mentioned adjustments to research projects, with 76 percent of mentors indicating that they adapted to COVID-19-related interruptions by switching from lab research to computational projects or research-related reading groups. Some mentors indicated that they did not need to adapt their research goals, because they had already conducted their lab work and were focusing on out-of-lab analysis or because they did not need lab access. Finally, mentors lamented the lack of a physical presence on campus, noting it was a detriment to both the

TABLE 3. Frequent Themes Repeated during Mentor Interviews, with Frequency, Definition, and Sample Quotes

Mentor themes	No. of mentors (n = 17)	Definition	Sample quote
Adjustments in projects	13 (76%)	Shifting to a different aspect of the project, finishing writing, continuing reading, or starting a new project	"What we did was we shifted everyone to a computational project. And I've always had some computational pieces to my research." – Mentor A
Care about students	12 (71%)	Addressing the safety and well-being of the students	"Just a lot of challenges for my students, and I just don't know how we can actually help them besides just encourage them to think positively, and just be more patient and more generous to the students." – CHL
Physical presence on campus	8 (47%)	Speaking on the lack of physical presence and its difficulties	"I want them to be able to see what other people are working on and participate in that atmosphere. So, I miss that. That's tough on the students—I know the FYRE student in particular." – John
Time issues	3 (18%)	Lack of time for mentors or students to adequately finish projects	"I've had to prioritize who gets most of my time because there's just not much to be had, including, you know, for me to do anything. So, my undergraduate students have gotten a lot less of my time because of that." – Mentor D
Weekly interaction	10 (59%)	Met with students consistently, often weekly, and students benefited	"I think they've mentioned several times about how much they appreciate still keeping our meeting times, even if they're briefer, [but] still keeping communication going to stay in touch." – Mentor B

students and mentors because of the loss of spontaneous interactions and discussion opportunities.

Impact on Students

Students most frequently mentioned specific research hardships and disappointments relating to the campus shutdown (see Table 4). For example, Andy set up his experiment in the first few months of the semester but was unable to continue it: "And so we're just ready to start taking data and then the whole COVID happened and nope, not happening. So that's kind of really just unfortunate." Students also reported difficulties outside of their research, including upheaval relating to sudden moves, working environments, and classes. For some, these difficulties turned into lost opportunities, including lost internships, lost interactions in physical space, and wishes for research that could provide balance with schoolwork. For example, Dakota stated, "So I miss it. Miss it so much. But yeah, that's about it. I feel like it made me appreciate it more now because before, towards the middle of the semester, [I was] also stressed. I really wanted a little [inside of the] lab." Students also showed resilience, with four students discussing how COVID-19 caused a shift in research to writing, reading, or other topics. Finally, for some, it was business as usual. This was either through a continuation of weekly meetings or an indication that no COVID-19-related shift occurred in their research activities or interactions.

Mentor-Mentee Pairs Analysis

There were four mentor-mentee pairs out of the 45 participants. The lack of pairs may be due to the recruitment call that was sent to all previous participants of the FYRE program and not specifically spring 2020 participants. Three students of the four pairs mentioned that there was no change or impact on their research, and the fourth (RockPaperGun) stated that the chemistry lab shut down. SS, the mentor, stated that she wanted to "give them some space," because the situation of going online was "unusual," especially "cop[ing] with online classes." RockPaperGun said he had "positive, longer interactions" with SS and planned on continuing research when the lab reopened.

Julian, a student who worked with Michael in meteorology, spoke about how it was "harder to get things accomplished online," but his mentor and others "dealt with the shutdown situation very well." Michael, on the other hand, spoke about how it would be easier to interact in person and that all but one student had been "ultra-enthusiastic." He said that the other student suffered from the transition to an online environment, conjecturing that the student was struggling with other classes that had transitioned to an online space. Malik, a student with Mentor A, did not have any changes with the shift online and said that he appreciated researchers, especially ones in the front lines of COVID-19 since he had begun researching. Mentor A

TABLE 4. Frequent Themes Repeated during Student Interviews, with Frequency, Definition, and Sample Quotes

Student themes	No. of students (n = 28)	Definition	Sample quote
Appreciate researchers when in pandemic	7 (25%)	Understanding of what researchers are going through, especially COVID-19 research	"If you didn't have that FYRE experience, you're just like, '. . .research is boring' . . . especially with COVID-19 going around, and people trying to find a cure. It helps me understand more of what's going on and how important it is for these health professions to actually find a cure for it." – Malik
Difficulties of researching	18 (64%)	Stating the hardships that were specific to research that occurred due to shutting down the campus	"It stopped everything. Because all our research is based in the lab, they can't really do much outside. Yeah, we can read literature and help with that. But … we need to troubleshoot some reactions that we can't really do right now anymore." – Christine
Lost opportunities	15 (54%)	Speaking of the opportunities lost or modified due to COVID	"I was going to present our paper at a conference in April, but [it] did not happen. So that was going to be cool as a culmination point of my research." – Emma DeAngeli
No change or impact	9 (32%)	Mentioning that there was no change or impact on the student from shutting down campus	"I can do most of my work through remote meetings and remote communications with people and connecting remotely to the computers in the department. So, I would say [research was affected] very hardly at all." – Ryan Hazlett
Outside of research difficulties	8 (29%)	Hardships that were outside of research that influenced participation	"Because of [moving], I didn't do any coursework for a week and was behind on the catch-up and all that. And, I also just don't have a good working environment like this. Where I'm at right now is not a proper desk. It's basically a dresser." – James
Shifts in research	4 (14%)	Writing or reading instead of doing research	"I was able to summarize what they had done in the past semesters. I didn't have anything of my own to present." – Katie
Weekly meetings	11 (39%)	Met with mentors or graduate students weekly and consistently	"We still have the same meeting schedule that we would normally. So, we have one group meeting every week and then we each have scheduled individual meetings that still occur." – Cora

had mentored many other FYRE students and kept emphasizing care of students (five times coded in the transcript), weekly meetings, and an adjustment to computational projects. Finally, prior to the shutdown, John had set up his student SF with the equipment necessary to conduct research on electrical engineering at home, so other than holding weekly meetings online, there was no change to or impact on their research.

Discussion

Consistent with previous literature that examined the changing environment brought about by disasters (Wright and Wordsworth 2013), these results suggest that COVID-19 inspired constructive and empathetic action by both mentors and undergraduate FYRE participants to ensure successful and continued collaboration over the remaining spring semester. Most mentors and students noted adjustments to projects, with a greater reliance on reading, computation, literature-based researching, and writing offsetting the halt in campus-based activities. However, compared to their mentors, students more often discussed these transitions as lost opportunities instead of as shifts in research. This may be in part due to time frame; many students were relatively new (having less than one semester of research experience) and were looking forward to the laboratory work or presenting, including the physical presence of researchers. This underscores the importance of professional development and networking as elements of the undergraduate research experience (Shanahan et al. 2015). Although both students and mentors also discussed weekly meetings and the stability those provided, students noted that it still lacked the physical environment conducive to spontaneous conversation, connections, and manipulation of research items that occurred especially in wet labs.

Differences between mentors' and students' perceptions regarding the effects of COVID-19 were also evident in, for example, the frequent citations of the pandemic by student interviewees as evidence of the importance of scientific research. One student, Robert Cascella, stated:

> I've just been hoping that the general public will see how important that science researchers are because they are our best chance of getting clinical studies done on drugs that could potentially be used or working on the vaccines that are in production. I just appreciate researchers more in times like this and I hope that everybody else does, too. Because without them . . . we wouldn't have anything.

Students also reported difficulties with the shutdown of campus, including both research challenges (e.g., not being allowed in the labs) and external complications (e.g., needing to do classwork amid a move home). Although mentors often used different language to discuss student challenges, meaning there was not a common theme in the coding, mentors commonly discussed their responses to the difficulties faced by the students. Twelve of seventeen mentors talked about their care for students such as adjusting their research expectations so that students can handle those difficulties. Mentoring literature suggests this care can make a huge difference in students' lives both in the short term (with psychological relief) and in the long term (with reconceptualizations of beliefs about the actions and mentoring of professors/researchers; Shanahan et al. 2015). Specifically, educators' emotional support for students can enhance student learning even at a distance (Cleveland-Innes and Campbell 2012), increase STEM student retention (Christe 2013), support ethnically diverse students in bridging perceived barriers (Amaro, Abriam-Yago, and Yoder 2006), help address students' psychological needs in the face of disaster (Wright and Wordsworth 2013), and improve student resiliency in response to disaster (Joshi et al. 2018; Warbington et al. 2019).

Although the FYRE program at OU provides substantial opportunities for students to professionally develop, neither FYRE nor the university provide formal training to faculty on the effective mentoring of students. This type of training in mentoring is uncommon at most institutions (Hund et al. 2018), yet responses from both faculty and students underscore the importance of mentoring relationships in weathering the COVID-19 shutdown. Mentor responses largely reflected an approach based around flexibility, communication, and empathy in their support of undergraduate researchers through the start of the pandemic. These are characteristics of successful mentoring often emphasized by mentor training initiatives (Hund et al. 2018; Keyser et al. 2008) such as focusing on emotional support (Opengart and Bierema 2015) and the importance of articulating and aligning expectations to the student's circumstances and goals (Limeri et al. 2019). When considered in the context of evidence-based practices of undergraduate research mentorship (Shanahan et al. 2015), the participants showed a strong commitment to four common practices:

1. Conducting strategic pre-planning of research (by creating a scope of research that had adjustments in projects)
2. Balancing rigorous expectations for research with emotional support and appropriate personal interest in students (by addressing the safety and well-being of the students)
3. Building community among members of the research team (through weekly meetings)
4. Dedicating time to one-on-one, hands-on mentoring (through both meetings and care for the students).

Broadly, mentor responses demonstrated the importance of being flexible in uncontrolled situations. This may help the students develop resources, communication, and trust—properties associated with becoming better scientist leaders (Hund et al. 2018). As all participants in this research were STEM students and faculty, these results suggest generalizable differences across a range of STEM fields. Whereas some students had no change due to the pandemic, others had to shut down all research labs and pivot their work. Physically-located labs were impacted in at least two ways due to COVID: the data could not be collected, and difficulties existed in attempting to replicate "spontaneous interactions" with others in the lab when online (as Ashley stated in her interview).

Interestingly, the results are consistent with findings of other research programs similarly impacted by the COVID-19 pandemic, emphasizing the importance of providing continuity in the research program despite the challenges posed by COVID-19 (Speer, Lyon, and Johnson 2021), increasing flexibility and support considering the virtual environment (Hall et al. 2021), and developing innovative ways to complete research goals (Bintliff et al. 2020). The analysis here also provides future insights into mentoring mentors: providing faculty with additional resources in the form of training programs or workshops on approaches to build in flexibility and demonstrate empathy may broaden their skill set and increase positive outcomes for students, even during (or especially after) a pandemic. Specifically, future consideration could also be given to delivery of effective mentoring, ways to think about different projects for difficult situations, comprehension of students' personal difficulties that can affect decisions about research time, and reconceptualization of opportunities to introduce undergraduate students to individual fields in STEM.

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Miloš Savić, Naga Rama Kothapalli
University of Oklahoma, savic@ou.edu, ramakn@ou.edu

Miloš Savić has been an associate professor in OU's Department of Mathematics since 2013. He earned his PhD from New Mexico State University and conducted his postdoctoral work at Michigan State University. He is currently researching in the areas of mathematical creativity and undergraduate research opportunities.

Naga Rama Kothapalli is an assistant professor in OU's Department of Chemistry and Biochemistry since 2017. She earned her PhD from University of Nebraska–Lincoln and conducted her postdoctoral work at the National Institute on Aging, National Institutes of Health. She is interested in developing course-based undergraduate research experiences in biochemistry and undergraduate STEM education. Her current work involves understanding the critical factors that influence a student's decision to pursue a career in STEM research. She is the principal investigator on the NSF grant that funded this work.

Hayley C. Lanier is an assistant professor in OU's Biology Department and an assistant curator of mammals at the Sam Noble Museum. She earned her PhD in biology from the University of Alaska Fairbanks. Her research is focused on using evolutionary ecology to inform conservation, with an emphasis on small mammals. She enjoys incorporating research into her courses and is part of the Squirrel-Net CURE leadership team.

Erin K. Freeman is an associate professor and master teacher of applied statistics in OU's Psychology Department. Her primary research interests focus on statistical pedagogy, undergraduate student success, and personality and individual differences in the experience of emotion. She earned her PhD in psychology from OU.

Lisa Ratliff is an undergraduate from Tulsa, OK who joined the Lanier Lab in fall 2018, with interests in museum collections and biodiversity outreach. Her projects have focused on using museum specimens to assess trends as well as testing for invasive DNA. She is pursuing her master's in science education with a focus on science communication.

St. Louis native Emma Hillermann graduated from OU with a bachelor of science in mathematics with minors in computer science and French. She is researching the impact of undergraduate research opportunities on students' academic growth.

Courtney Martin recently graduated from OU with a bachelor of arts in psychology. She is a research assistant on the impact of undergraduate research opportunities on students' academic growth.

OTHER FEATURE ARTICLE

Undergraduate Research Abroad: Shared Themes in Student Learning from Two Models of Course-Embedded Undergraduate Research in Field Biology Study Abroad Courses

Jennifer A. Hamel, *Elon University*
Hannah M. ter Hofstede, *Dartmouth College*
Adrienne Gauthier, *Dartmouth College*
David Lopatto, *Grinnell College*
Prudence Merton, *Dartmouth College*
David Vandermast, *Elon University*

Abstract

Few studies have investigated the effects of combining undergraduate research with study abroad. The authors present student self-reported learning gains from two undergraduate courses that embed research within study abroad courses. Students in one course worked in small groups on original research projects; students in the second course collectively contributed to one ongoing, professional research project. Student learning was evaluated through focus groups, reflective journaling, and surveys. Students from both courses reported gains unique to research in an international context, including curiosity inspired by novel environments and valuing local knowledge for site-specific questions. Differences in student learning between courses raise questions about the relationship of course structures to high-impact practices and their potential to affect learning in opposing or synergistic ways.

Keywords: *course-embedded undergraduate research, CUREs, high-impact practices, study abroad, undergraduate research*

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It is widely recognized that science students must learn the practice of science as well as science content (AAAS 2011; Boyer Commission 1998; President's Council of Advisors on Science and Technology 2012), and students who participate in mentored, one-on-one research report diverse benefits (Lopatto 2004; Nagda et al. 1998; Russell, Hancock, and McCullough 2007; Seymour et al. 2004). Like undergraduate research, study abroad is considered a high-impact practice (Kuh 2008), and it can benefit students by increasing cross-cultural sensitivity and intercultural competence (Anderson, Lorenz, and White 2016; Rexeisen 2013). However, despite interest in combining multiple high-impact practices (Goeltz and Duran 2018), there is limited literature on potential intersections between study abroad and undergraduate research, and the potential effects of a combined experience on student outcomes (Bender, Wright, and Lopatto 2009; Bender, Yaffe, and Lopatto 2017; McLaughlin et al. 2018; Shostya and Morreale 2017).

One approach to combining study abroad and undergraduate research is to embed individual students within host research groups outside the United States (Bender et al. 2009, 2017; Goeltz and Duran 2018). Although this type of experience achieves desired outcomes related to both undergraduate research and study abroad, not all students are developmentally ready to embark on the dual challenge of solo international travel and individually mentored research. Additionally, mentoring one-on-one undergraduate research experiences (UREs) internationally may be cost-prohibitive at small, primarily undergraduate institutions. One alternate approach is to embed a research component within a short-term study abroad (STSA)

TABLE 1. Characteristics of Students Enrolled in Elon Field Biology Panama and the Dartmouth Biology Foreign Study Program

Course	Elon Field Biology Panama (BIO 335)	Dartmouth Biology Foreign Study Program (BIOL 55, 56, 57)
Gender	4 female 4 male	7 female 6 male
Ethnicity	8 White	9 White 3 Asian 1 Pacific Islander
Year	1 second-year student 5 third-year students 2 fourth-year students	10 third-year students 3 fourth-year students
Majors	2 biochemistry 3 biology 1 biology with teacher licensure 2 environmental studies	8 biology 1 economics 1 engineering 1 environmental studies 1 neuroscience 1 undeclared
Prior research experience	3 yes (semester or summer) 4 no 1 NA/prefer not to answer	12 yes (semester or summer) 1 no
Postgraduation plans, precourse	1 MS in STEM 2 PhD in STEM 2 MD 1 health professions 1 teaching 1 Other	3 MS in STEM 3 PhD in STEM 2 MD 0 health professions 0 teaching 5 Other

course (Shostya and Morreale 2017). STSA courses are employed by many institutions, and STSA courses in the life sciences may be customized to include a minimum of two models of UREs: short-term individual or small-group projects and course-based undergraduate research experiences (CUREs). In a CURE, a class of students contributes to an original, collaborative research project, engaging students in professional research (Auchincloss et al. 2014; Linn et al. 2015).

This study sought to evaluate the effects of two upper-level STSA courses with embedded UREs on student gains related to research and intercultural competence. Also examined was whether students enrolled in both courses reported gains related to combining the high-impact practices of undergraduate research and study abroad, despite differences in course structures, durations, locations, and models of undergraduate research used. Findings from both course models may assist those at diverse institutions, as a particular model may be more feasible or better aligned with educational goals depending on the type of institution.

Methods

Institution and Participant Information

The two courses in this study were offered through the Departments of Biology at Elon University (Elon, NC) and Dartmouth College (Hanover, NH). Each course was an entire term, but term lengths differed (Elon: three-week January term, Dartmouth: nine-week winter term, January–March). Participants in both courses were undergraduate students enrolled in STEM majors, with one exception (see Table 1). Most participants from both institutions were White and third-year students, and both courses included nearly equal numbers of self-identified male and female students. Half of the Elon students had no prior research experience, whereas only one of 13 Dartmouth students had no prior research experience.

Instructional Design

To assess potential student learning gains at the intersection of undergraduate research and global engagement, two URE models were embedded within STSA courses. Both courses engaged upper-level life science majors in tropical ecology content and research. Elon's course was a three-week, upper-level field biology course situated in three bioregions within Panama. During the first two weeks of the course, students learned tropical ecology research methods through inquiry-based field activities such as quantifying forest diversity. During the final week, students contributed as a cohort, via a CURE module, to an ongoing, professional research program at the Smithsonian Tropical Research Institute (STRI) on Barro Colorado Island (BCI). Students from Dartmouth participated in a nine-week, upper-level, field biology course situated at eight field sites in Panama, Costa Rica, and Little Cayman Island. At most field sites, students designed and executed autonomous research projects in small groups. During the course's first week, students were introduced to the same professional research program to which the Elon students contributed, and they were encouraged to design a project that complemented the ongoing research. Courses therefore differed in duration, number of locations, number and student autonomy of UREs, precourse preparation, and content (see Table 2; Hamel Lab n.d.)

TABLE 2. Differences between Elon Field Biology Panama and the Dartmouth Biology Foreign Study Program

Course	Elon Field Biology Panama (BIO 335)	Dartmouth Biology Foreign Study Program (BIOL 55, 56, 57)
Goals (from syllabus)	"In this course, students will visit four ecologically and culturally distinct sites, quantify forest and marine invertebrate biodiversity, and contribute to an ongoing professional research project on insect behavioral ecology . . . Dedicated students will gain experience conducting ecological research in tropical environments, explore Panamanian perspectives on ecology, conservation, and the value of basic science, and broaden their competence navigating a different culture."	"Students are challenged to know, understand and appreciate the diversity of form and function in organisms, and the interactions that generate the often-spectacular patterns they see in the field. Students master field and analytical methods (including hypothesis testing, statistical and software skills) for observational and experimental research. Students practice contemporary scientific inquiry: making observations, asking testable questions, generating hypotheses, developing experimental protocols, collecting data, making statistical inferences, writing scientific papers, and presenting seminars."
Prerequisites	First-year organismal survey course, second-year ecology and evolution course, or permission of instructor	Foundation course in ecology; students with courses in ecology methods and statistics are given preference.
Predeparture preparation	1 credit-hour course, fall semester 14 predeparture meetings, two hours each (28 hours)	Three predeparture meetings (3 hours) Social gatherings with previous course students for peer-to-peer advice Logistics arranged by email and course website
Research model	Full cohort CURE module	Mentored small-group projects
Research experiences	Three modules of mentored field research activities, three days each One five-day CURE module	Nine iterations of mentored small-group field research projects, 1 week each
Course duration and credit hours	22 days (winter term), 4 credit hours	Nine weeks (quarter), 3 courses[a]
Course locations	Five sites in Panama: Panama City (orientation only) La Amistad National Park (Chiriquí) Boca del Drago (Bocas) Soberanía National Park (Gamboa) STRI Barro Colorado Island	Nine sites in Panama, Costa Rica, and Little Cayman Island: STRI Barro Colorado Island, Panama San Jose, Costa Rica Palo Verde OTS Research Station, CR Santa Rosa National Park, CR Monteverde Biological Station, CR Cuerici Biological Station, CR Campanario Biological Station, CR Las Cruces OTS Research Station, CR Little Cayman Research Center, CCMI, Little Cayman Island
Cultural/immersion experiences	In-country orientation activities Homestay with local families Meetings with local nongovernmental organizations Cohort stays in family-run hostels Cohort stay at field station	Cohort stays mostly at field stations Camping at Santa Rosa, CR Hotel in San Jose, CR
Assessments	Module content quizzes (4) Research presentations (in pairs) Research papers (individual) Iterative reflective journaling	Student-initiated research projects (small groups) Presentations of primary literature articles Natural history quizzes (2) Field notebook and journaling Teamwork skills and participation

Note: [a]Dartmouth College does not use credit hours but rather requires that students complete a number of courses (35) prior to graduation.

Elon University Field Biology Panama

Course structure and logistics. Students participated in a one-day orientation and four course modules in Panama during January 2019. The four course modules focused on forest, coral reef, avian, and insect behavioral ecology. Students were instructed and mentored in all modules by the authors and scientists associated with STRI. The School for International Training provided orientation activities, logistical support, and coordination of instruction for the first three course modules. An intentional component of the Elon course was embedding students with community members early in the travel course. During the first module, Elon students therefore lived with local families in a nearby agricultural community. During the coral reef and avian ecology modules, students lived at local hostels with their instructors, as well as with guests unaffiliated with the course. The insect behavioral ecology module was conducted over five days at the STRI BCI field station, where students lived in dormitory housing.

Course content and activities. During the first three modules, students were trained in field methods and sampled the diversities and abundances of focal organisms (plant families, coral types, and bird species, respectively). The field activities were application opportunities for lecture content, and lectures and field activities were led onsite by STRI ecologists with support from the authors and SIT personnel. During the insect behavioral ecology module, students contributed as a cohort to an ongoing research study of insect communication on BCI, constituting a CURE module as outlined by Auchincloss and colleagues (2014). Students were introduced to the theoretical framework, aims, and recent findings of the research program by study authors Jennifer A. Hamel and Hannah M. ter Hofstede, met with near-peer mentors from the research group (postdoctoral fellows, graduate student, technician, and advanced undergraduate student) and observed insects in the field and laboratory. Elon students worked to choose an unresolved question that could advance the research program, derived a hypothesis and predictions, designed an experiment to test their predictions, executed the experiment twice (revising methods between iterations), and analyzed data from both iterations of the experiment.

Course assessments and products. During each module, student learning of course content was assessed with a written quiz of open-ended short essay questions, and the personal and cultural experiences of students were assessed via their written responses to journal prompts. For the final module, students wrote a reflection on both the module and the entire course based on modified prompts (see Table 3).

Dartmouth College Biology Foreign Study Program

Course structure and logistics. The Dartmouth program occurred over the nine-week winter term of 2019, visiting nine locations in Panama, Costa Rica, and Little Cayman Island. Logistics for travel, accommodations, and local orientation were provided by STRI in Panama, the Organization for Tropical Studies (OTS) in Costa Rica, and the Central Caribbean Marine Institute on Little Cayman Island. Students spent the first night at a hotel in Panama City, followed by six days at BCI. The course then spent five weeks at eight locations in Costa Rica and traveled to the Central Caribbean Marine Institute on Little Cayman Island for the remaining three weeks of the program. Accommodations were dormitory-style. Course content was provided by Dartmouth faculty (one–two professors at each site and two PhD student teaching assistants for the entire program).

Course content and activities. Course content was delivered during one–two instructional modules per day, including lectures, labs, and scientific article discussions. The main focus of the program, and majority of the time spent, was on original research projects. At six locations, students conducted research projects of their own design. Site-specific orientation was provided by local guides or station staff, followed by group brainstorming for location-specific research questions. Students formed small groups that developed hypotheses, designed experiments or observational studies, collected and analyzed data, and presented results to the class. At the next site, students started a new project while writing a manuscript for the previous location's project. These manuscripts are published in the course journal (see Dartmouth College n.d.; Hamel Lab n.d.).

Course assessments and products. Students were evaluated based on their progress in understanding and communicating the nature and practice of science. This included asking interesting research questions that address a larger theoretical model and generate testable hypotheses; designing studies that test hypotheses with logical treatments, controls, and alternative predicted outcomes; incorporating multiple lines of evidence when possible; collecting and statistically analyzing data; and effectively communicating results through figures and in writing. Because some students had more research experience than others, evaluation was based on individual development and progress. Although projects were conducted in groups, students and faculty worked closely at every stage, allowing faculty to assess how individual students adjusted their approach to research during the course (see Symes, Serrell, and Ayres 2015 for details). Students were also graded on their final manuscripts, field notebook, primary literature presentation, and discussion participation as well as two quizzes. Halfway through the course, students were given two questions about the effects of the course locations on their learning and efforts made to learn about the culture of the places visited by the course (see Table 3). Students were asked to answer these questions in their journals, with the goal of encouraging greater cultural awareness.

TABLE 3. Prompts from Written Reflections and Focus Groups for Each Course

<table>
<tr><th colspan="2">Reflective journal prompts</th></tr>
<tr><td colspan="2">Focus group prompts (both courses)
• How were your experiences similar to / different from your expectations before you left campus?
• How has your thinking about international travel changed as a result of this experience?
• How has your thinking about Central America changed as a result of this experience?
• How has the course affected your thinking about research?
• How has the course affected your thinking about who conducts research?
• How did your research experiences compare to how you imagine they would have been in the US?

Comment on what you learned during the module on Barro Colorado Island.
• How has your knowledge about tropical ecology changed as a result of this experience?
• What advice would you give future students taking this course?</td></tr>
<tr><td>Dartmouth (mid-course reflection)</td><td>1. How do you think your experience of this course would be different if it was conducted in the US instead of Central America?

2. The main purpose of the Bio FSP is to cultivate your development as a scientist and expose you to neotropical ecosystems. However, given that we conduct the course in Central America, what opportunities have you taken to learn more about the cultures and people of the locations we visit?</td></tr>
<tr><td>Elon (end-of-course reflection)</td><td>In your reflection paper, compare your expectations, predictions, and understanding about the topics below before you began travel with what you learned through your experiences in the course. To do so, consider the goals of the course, the predeparture reflection that you wrote during the fall semester, information discussed during fall semester, and the experiences you had in Panama to write a reflective essay.
Topics that should be included in this paper:

• Your interactions and conversations with our hosts and instructors in Panama
• What you learned about their lives and society

• What you learned about research careers and ecological researchers
• What you learned about the research process

• How the course was similar to / different from your expectations before you left Elon University
  • How your thinking about international travel has changed
  • How your thinking about Central America has changed

• How your knowledge about the following topics has changed:
  • Community diversity and structure of tropical forests and reefs
  • The impacts of anthropogenic activities (e.g., climate change, agriculture, hydroelectric power, tourism) on tropical forests, reefs, and human communities

Finally, please close with a short paragraph of advice that you would offer future students taking this course. Your comments are valuable to us as we work to improve this course.</td></tr>
</table>

Evaluation of Student Opinions and Learning Gains

Students in both courses completed predeparture surveys to assess student prior research and coursework experience, motivation for taking the courses, and opinions and attitudes about science. To evaluate learning outcomes, students in both courses engaged in reflective journaling during the course and participated in focus-group interviews after returning to their respective campuses. Evaluation of learning outcomes for the Dartmouth course also included surveys with Likert-scale items and therefore employed a mixed-methods approach; regrettably, postcourse surveys from the Elon course included a printing error and could not be evaluated.

Surveys. Predeparture surveys were modified from the Classroom Undergraduate Research Experience (CURE) survey, a validated instrument for assessing student self-reported learning gains associated with the nature of science, research skill development, and attitudes toward science (Lopatto 2008). Students in the Dartmouth course also completed postcourse surveys that assessed self-reported learning gains associated with research and changes in opinions and attitudes about science for 21 items using a 5-point Likert scale. Like the predeparture surveys, the postcourse surveys were modified from the CURE survey. By including most items from the CURE survey, students' self-reported learning gains could be visually compared with those from thousands of previous responses from students at other institutions. The modified CURE surveys used in this study are available at an author's lab website (see Hamel Lab n.d.).

Reflective journals. Students in both courses engaged in reflective journaling in response to open-ended prompts, but prompts and timing of journaling activity differed between courses (see Table 3).

Focus groups. After participants returned to the United States, students from both courses were invited to participate in confidential focus-group interviews. Seven Elon students and 11 Dartmouth students provided qualitative assessment of their experiences in such discussions on their respective campuses. Goals for the focus groups included the encouragement of student reflection on course experiences, personal responses, and group discussion. Other evaluation methods were focused on individuals, seeking to discover salient themes that might emerge through interactive discussion of shared memory. Focus-group prompts were open-ended and written by the authors before the courses began (see Table 3). Faculty and staff trained in qualitative assessment from the Elon Center for the Advancement of Teaching and Learning and Dartmouth Learning Design and Technology facilitated the focus groups on their respective campuses, and each focus group included two to four students. Study authors Adrienne Gauthier and Prudence Merton identified themes in focus-group transcripts and reflective journals through holistic analysis. Students who completed surveys and participated in focus groups received $25 gift cards.

Results

Motivations for Enrolling in Research Abroad Courses

Student responses to the precourse surveys suggest that most students from both institutions took the course to learn about ecological research and gain research experience, but learning about other cultures was also important. Students from both courses ranked interest in the subject matter as one of the most important factors in their decision to take the course (see Figure 1). Dartmouth students also ranked learning more about their world, science, and the research process as highly important; Elon students ranked obtaining hands-on research experience and personal growth as their other most important factors. Students from both courses ranked improving foreign-language skills among the least important motivations for taking the course. Dartmouth students ranked filling a distribution requirement and seeking an easy course fit into their schedule as least important, whereas Elon students also ranked needing the course for employment after college or for graduate or professional school as least important.

Gains Associated with Content Learning and Research Experience in a Global Context

Both Dartmouth and Elon students commented in written reflections and focus groups on benefits associated with course locations (see Table 4). Students from both courses reported novelty, excitement, and a sense of wonder in response to tropical biodiversity. Several Dartmouth students mentioned feeling "challenged" to be more "creative" in their research than they would have been in the United States and that course locations offered unique experiences that would not have occurred in the United States. One Dartmouth student commented on the importance of "local knowledge" to understanding issues and problem-solving. Three Dartmouth students remarked that if the course had been located in the United States, it would have been "harder to unplug," and some Dartmouth students with previous research experience noted that the course demonstrated that research does not require technology-enabled laboratory environments. One student said, ". . . cool to see that you can get some pretty decent answers with very little technology. . ."

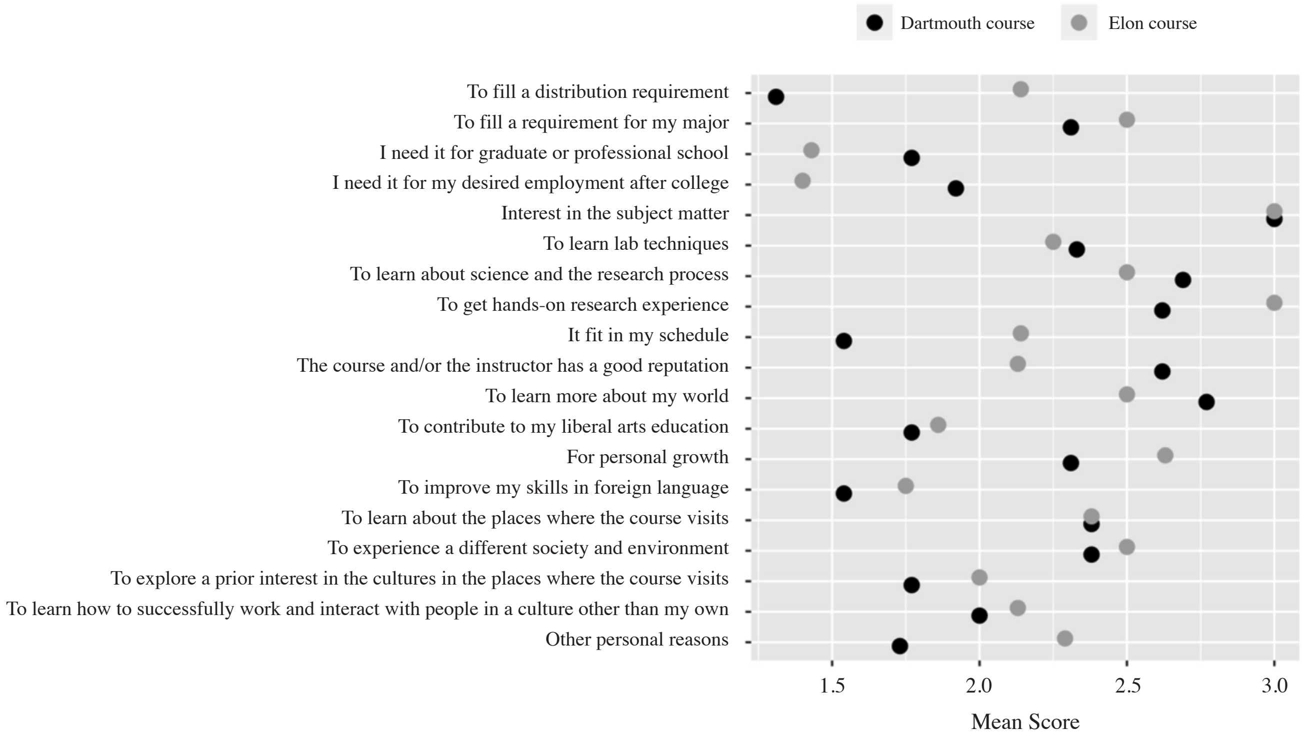
Several Elon students conveyed surprise at the effect of context on their learning about tropical ecology. Elon focus-group participants commented on the high biodiversity of their learning contexts, the ability of differences between the tropical environments and "home/Elon" to engage their curiosity and interest, and the growth of their appreciation of these differences as they began to engage in research activities.

In response to a prompt about location-specific anthropogenic effects, several Elon students described seeing these effects firsthand as motivating and compelling. Other students spoke about how it felt to make such observations while building rapport with host-country nationals. They reported that witnessing coral-reef degradation while working with researchers trying to mitigate those effects strengthened their commitment to stemming climate change.

Gains in intercultural competence and personal growth. Both Dartmouth and Elon students commented on course benefits related to intercultural competence and personal growth (see Table 4). Students from both courses reported initially feeling tentative or anxious about traveling outside the "bubble" (where "bubble" sometimes referred to the institution/program and sometimes the United States), but during and after the courses, they commented on the invaluable experience of immersion in another country. Students in both courses who had studied Spanish appreciated the opportunity to use foreign-language skills with host- country nationals, although the depth and extent of those conversations varied according to the students' fluency.

All eight Elon students commented in their reflection papers about the positive effects of interactions with host-country individuals, noting that the diverse Panamanians with whom they interacted were kind to outsiders, and that such interactions helped them feel welcome, safe, and inspired. Most Elon students noted the high value placed by Panamanians on family, relationships, and spending time together, and many contrasted that valuation to their perception of values in the United States. Stays with host families at the beginning of the course appeared to motivate Elon students to clarify their personal values.

FIGURE 1. Mean Scores for Precourse Survey Statements Related to the Reasons Students Enrolled in the Elon and Dartmouth Research Abroad Courses



Note: Scores rate the importance of each reason for the student's decision to take the course (1 = not important, 2 = moderately important, 3 = very important). Sample sizes were $n = 8$ (Elon) and $n = 13$ (Dartmouth).

Some Dartmouth students commented about the effect of the global experience on their perspective on values. Several Dartmouth students indicated that constraints such as time and location, as well as their own decisions, limited the number and nature of their interactions with host-country individuals and that intercultural experiences were limited.

Learning gains associated with research. Dartmouth and Elon students also commented on learning gains associated with research (see Table 4). Students from both courses reported that their perceptions about who conducts research changed as a consequence of their experiences, particularly as a consequence of their interactions with researchers and instructors in the courses. In an Elon focus group, the facilitator asked, "How has the course affected your thinking about who conducts research?" One student responded, "You know . . . anybody," and was echoed by another student, "Yeah, I think just anyone who wants to. Especially because, everyone [instructors during the course] had such diverse backgrounds. Some people just . . . casually stumbled into it somehow. . . . It's like, anyone can do it." Anecdotally, six of the eight students in the Elon course sought out additional, postcourse research experiences.

In addition to changing their perceptions about who can conduct research and the feasibility of making it part of their own identity, students from both courses also changed their perceptions about the goals and activities associated with research. Students in both courses reflected on the role of failure and setbacks in research. Elon students commented that research frequently does not proceed as expected and that engaging in the research process enhanced their understanding of journal articles. One student commented, "When I read the methods section in a research paper, I will finally understand the amount of work that goes into that."

Students from both courses expressed enthusiasm for projects in which they could choose topics that interested them and develop their own question(s). For Dartmouth students, this was true of all projects; for Elon students, this was only true of the CURE module. Students from both courses also discussed the collaborative nature of research and commented about their realization that the results of their projects mattered to others in the scientific community.

Survey results: Learning gains associated with research from the Dartmouth course. On the postcourse survey, all the Dartmouth students gave the highest possible score (extensive gains in learning) for working on a project of their own design; working in small groups; being

TABLE 4. Themes and Representative Comments from Students Who Participated in Postcourse Focus Groups

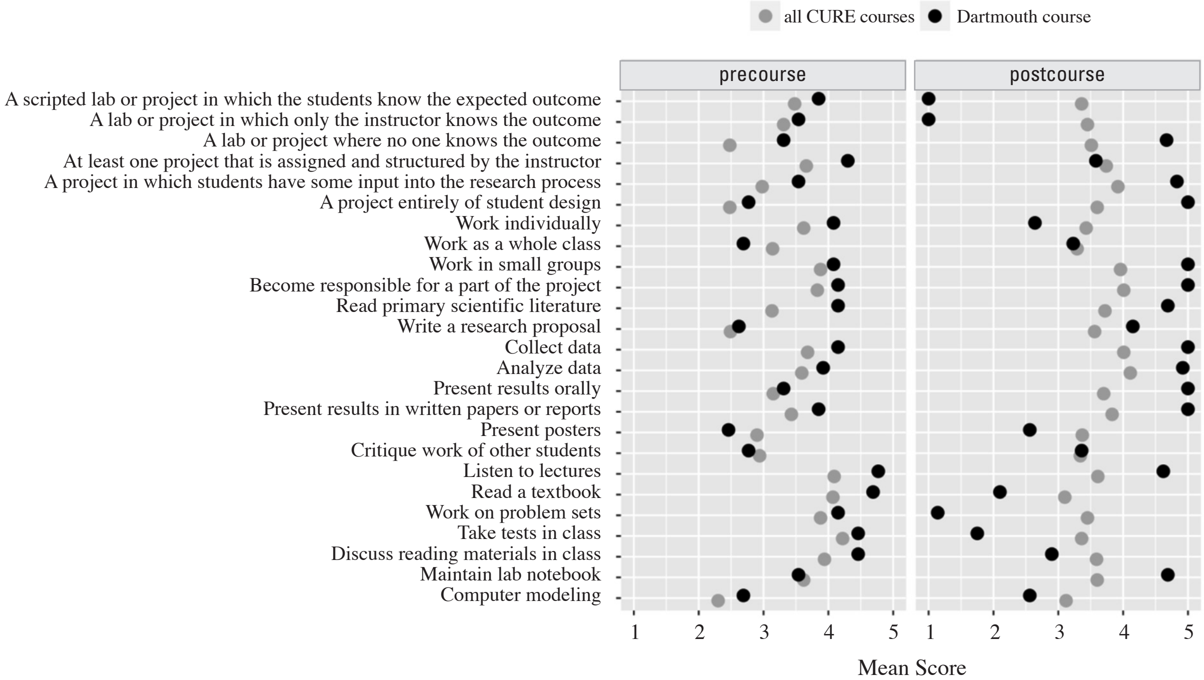
Content learning and research experience in a global context	
Effect of context on sense of wonder and scientific thinking	"I think that in a familiar natural environment, it is easy to have preconceived ideas about the system functioning of that environment whereas when placed into an entirely new landscape it is much harder to have previously drawn conclusions. . . . [here] I feel that I'm more likely to ask questions that could lead to a real understanding. . . ." – Dartmouth student
Effect of context on learning about tropical ecology	"It wasn't like . . . I could only do this in Panama, but I feel like Panama was the best place for this." – Elon student "I knew that rainforests are some of the most diverse places on Earth, but seeing all the different species in person and comparing the diversity index to (indices of) forests in North Carolina really brought that point home." – Elon student
Observation of anthropogenic effects	"[t]here is something strange about seeing the effects of humans [on climate change] in person compared to hearing about it during lecture. I guess you don't realize how real it is until you're looking at it. . . ." – Elon student
Intercultural competence and personal growth	
Motivation to engage with host country nationals and use foreign-language skills	"I want to continue to push myself to engage with people, despite my nervousness surrounding my Spanish-speaking abilities, so that I can continue to learn about the culture and life here in Costa Rica while I experience learning about the biology of this country's natural world." – Dartmouth student "I have mainly been a sight-seer. I have conversed with a few people of Central America, but I have not taken much initiative to engage in direct interaction." – Dartmouth student
Clarification of personal values	" . . . made me think about myself and how I need to value my connection with other people more than I value less important things." – Elon student "[US citizens put] . . . work ahead of everything else . . . [there is] so much tension and stress [at home], I wish people would relax more and just enjoy life." – Elon student
Awareness of diversity and differences	". . . I really enjoyed traveling and experiencing things that I have never experienced before. . . .You become more aware of different people and cultures and start to understand yourself a little bit more." – Elon students
Culturally specific relationships with the environment	"Hearing perspectives and values [from] people [in] another language has challenged me to think about how this country has a distinct culture surrounding the environment which is quite different than the culture and values of the environment in the US. This has given me a special chance to think about my own values and how my upbringing has given me an intrinsic value for nature that not all of my peers in the US have." – Dartmouth student
Research experience	
Increased interest	". . . I see it's more possible to do research . . . meeting all the different professors that we had in Panama . . . seeing different aspects of science . . . it's definitely possible and interesting. Something I would be more into now." – Elon student
Understanding of who does research; increased sense of competency	"I kind of wrote research off as a career path, because I was . . . scared that you have to be really smart . . . doing it or seeing other people doing it made it seem like they're just regular people and it's possible." – Elon student "I didn't really know how to feel about research. . . . I think it's [the travel course] definitely changed my view . . . anyone can do research . . . if they're interested in the subject." – Dartmouth student
Increased understanding of the goals of research	"I thought it was really neat that . . . compared to some of the courses I've taken in the past where you kind of know the expected outcome of the research project you're working on, you really didn't know what to expect with our research projects; so it was kind of like a process of discovery which is really exciting." – Dartmouth student
Setbacks are a normal part of research	"[it is] okay for experiments to not go as planned, [that] does not mean it's a failure . . . still a good learning moment and now we know how to improve the next time" – Elon student ". . . you don't have to have everything figured out right away, which was something I definitely needed to hear." – Elon student
Enthusiasm for agency	". . . it was really rewarding to do something that was less structured because you could . . . choose a project that was really interesting to you and that you . . . personally were either interested in or passionate about." – Dartmouth student "I don't think I ever expected that we would be given so much freedom in terms of what we wanted to do, what we wanted to study. So that was really surprising and a really positive experience for me." – Dartmouth student ". . . because we got to design it there was a lot more ownership that I felt and there was an excitement that we all had..." – Elon student

(*table continues*)

TABLE 4. (cont.)

Research experience	
Research is collaborative	"…everyone was doing . . . a little piece of the project. . . . they were working as a team and . . . bouncing ideas off of each other and even if it was someone's specific project you had other people going out with them . . . " – Elon student
Research happens in a community	"I also got really excited about it because there were some grad students doing research there [at BCI], and they were super interested to hear about the results of our study because it would have some sort of application to what they were doing . . . it's good to feel like what I'm doing actually . . . has some sort of effect on somebody else's research, and . . . they'll actually care about it." – Dartmouth student

FIGURE 2. Mean Scores for Survey Statements Related to Course Elements for the Dartmouth Course and CURE Surveys from Other Courses

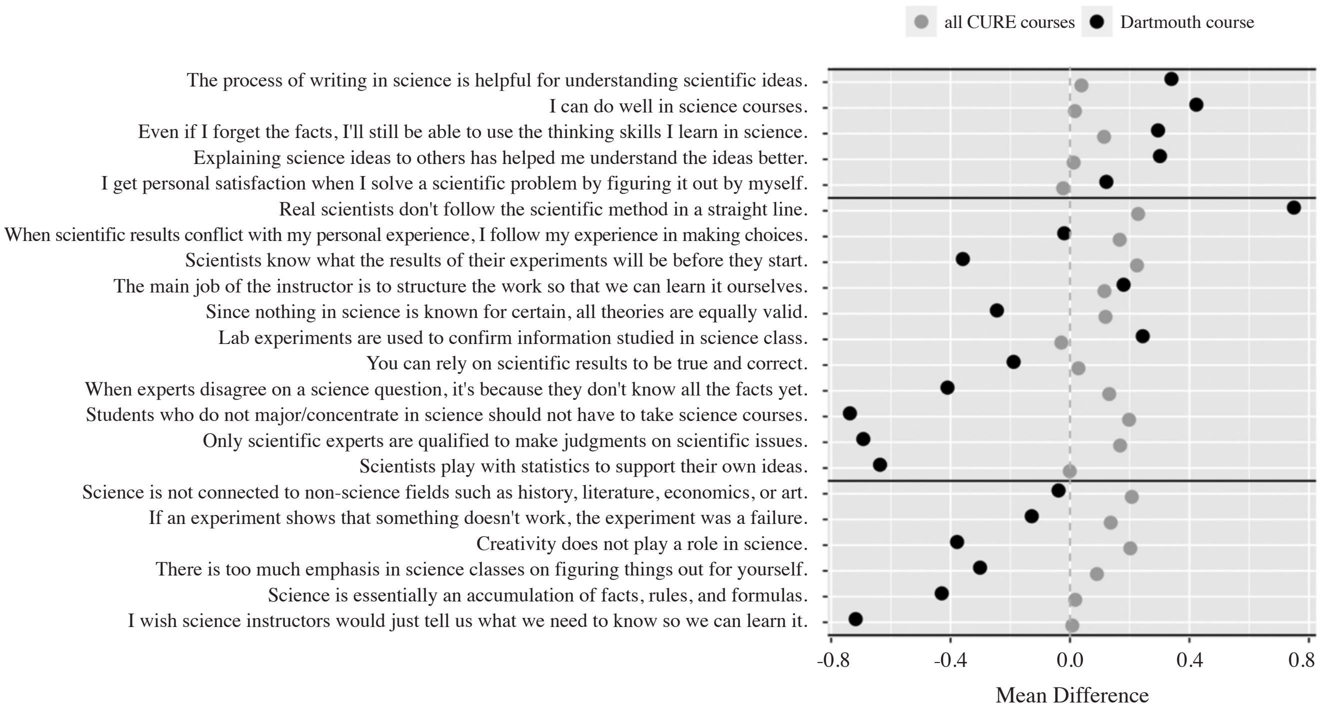


Note: Precourse survey responses reflect a student's estimate of personal experience and ability in each course element prior to the course, whereas postcourse survey results reflect a student's perceived gain in ability due to the course. Scores rate the level of experience (precourse survey) or gain (postcourse survey) as 1 = none, 2 = little, 3 = some, 4 = much, 5 = extensive. Sample sizes were $n = 13$ (Dartmouth) and $n \leq 17{,}680$ (other courses).

responsible for a part of the project; and collecting data and presenting their results, both orally and in writing (see Figure 2). Unsurprisingly, elements that did not exist in the Dartmouth course received the lowest and fewest scores (working on problem sets—a scripted lab/project where students know the outcome and a lab/project where only the instructor knows the outcome). Although these elements were generally scored higher and lower respectively by the CURE survey for all courses, Dartmouth scores were much higher at the high end and much lower at the low end compared to the CURE survey results in general. Data from other courses was included for visual comparison only.

To learn how student opinions about science were influenced by the course, the difference in the ratings between the precourse and postcourse surveys was calculated for each individual for each question (i.e., the score from the precourse survey subtracted from the score from the postcourse survey). Means of these differences suggest that Dartmouth students' opinions about science learning were influenced by the course (see Figure 3). Specifically, students scored higher on statements reflecting a positive attitude toward science learning and lower on statements reflecting a negative attitude toward science on the postcourse survey compared to the precourse survey (see Figure 3). These differences were greater than the average

FIGURE 3. Difference in Mean Scores between Precourse and Postcourse Surveys for Statements Related to Student Opinions about Science for the Dartmouth Course and CURE Surveys from Other Courses



Note: Students scored their agreement with statements as 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. A difference of zero (gray dashed line) indicates that, on average, student opinions about the statement did not change between the start and the end of the course; positive values indicate that students show an increase in agreement with the statement after the course; negative values indicate that students show a decrease in agreement with the statement after the course. The top five statements reflect a positive attitude toward science learning, whereas the bottom six statements reflect a negative attitude toward science learning. Sample sizes were $n = 13$ (Dartmouth) and $n \leq 17{,}680$ (other courses).

seen across many CURE courses. Dartmouth students also showed a large increase in agreement with the statement that scientists do not follow the scientific method in a straight line and large decreases in agreement with statements suggesting that scientific knowledge should be or is the exclusive purview of scientists and that scientists play with statistics to support their own ideas.

Dartmouth students also rated the perceived benefits gained from the course. On average, Dartmouth students rated gaining skills in science writing, becoming part of a learning community, building tolerance for obstacles during the research process, and achieving readiness for more demanding research as the greatest benefits of the course. These benefits reflect the focus on iterative independent research projects throughout the course. In general, Dartmouth students rated their gains higher than the average for CURE surveys (see Figure 4). However, they reported only moderate gains in learning ethical conduct, becoming proficient in laboratory techniques, and working independently.

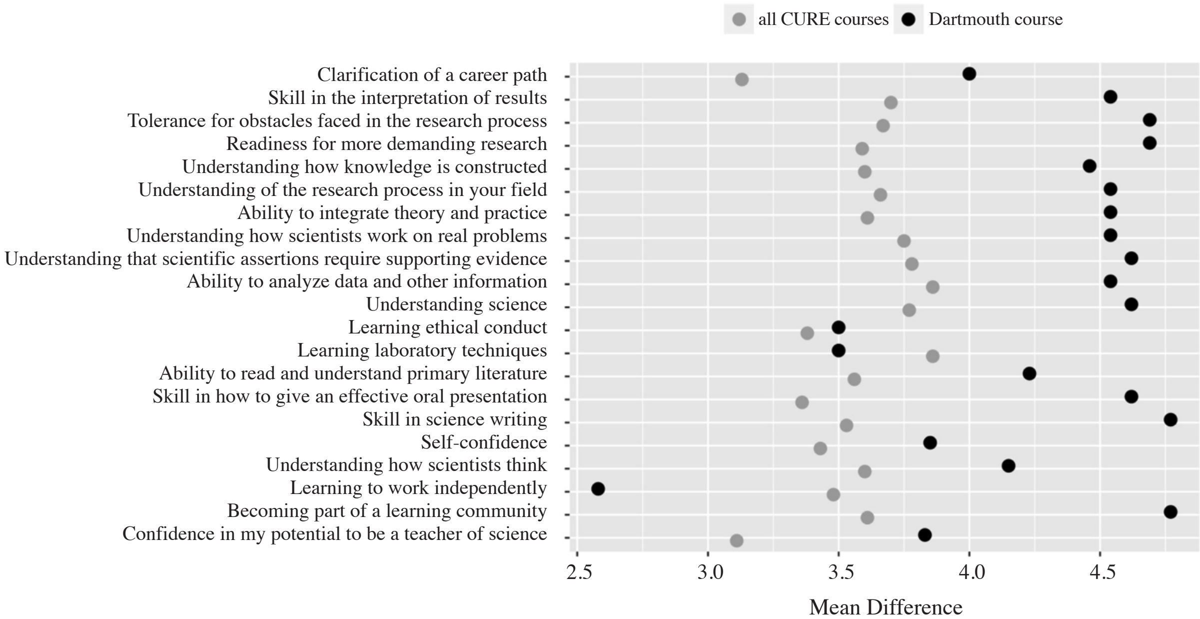
Discussion

Themes Shared by the Two Courses

Despite numerous differences in structure and content between the courses, some common themes for student learning gains were found (see Table 4). First, students from both courses reported learning gains associated with conducting research in study abroad contexts, suggesting that some unique benefits were achieved by combining high-impact practices. For example, Dartmouth students noted that the novel tropical forest environments awakened their curiosity, demanded their creativity, and illustrated to them that research can be conducted outside of laboratories and without high-tech equipment. Students from both courses also described how abstract science content was made real for them through immersion in tropical environments. Most Elon students described positive effects of building professional relationships with Panamanian guest instructors while studying their focal ecosystems alongside them, particularly as they reflected on anthropogenic damage to ecosystems. Importantly, both Dartmouth and Elon students recognized that both ecosystem-specific and culturally proficient expertise was needed to conduct research in these contexts.

Findings from both courses suggest strong learning gains for research, tropical ecology content, and the nature of science, but students reported fewer gains associated with personal growth and intercultural competence, and students from both courses commented that the tight

FIGURE 4. Mean Scores for Survey Statements Related to Learning Benefits for the Dartmouth Course and CURE Surveys from Other Courses



Note: Scores rate the student's perceived gain in benefits as 1 = no gain or very small gain, 2 = small gain, 3 = moderate gain, 4 = large gain, 5 = very large gain. Sample sizes were $n = 13$ (Dartmouth) and $n \leq 17{,}680$ (other courses).

research focus of each course limited their opportunities for learning about the cultures and communities of course locations. This outcome was anticipated, given the aims of each course, but was also likely influenced by instructor expertise and the cohorted nature of the courses. All of the Dartmouth and Elon course instructors are researchers with disciplinary expertise in ecology, with more limited experience in pedagogy related to intercultural competence. Activities related to intercultural competence were incorporated intentionally (e.g., reflective journaling in both courses, cultural orientation in both courses, and homestays in Elon's case), but the heart of each course still reflected disciplinary expertise.

Differences in Student Learning Gains between Courses

There were also some interesting differences in participant responses between the two courses. Due to the small sample size, it is not possible to say that these differences necessarily reflect differences between the two courses, but they are suggestive and provide potential topics for future research. Although students in both courses reported learning gains associated with research and positive shifts in their perceptions of research, the nature of these gains differed between courses. Some of these differences likely reflect real differences between the cohorts. For example, in focus groups, some Elon students expressed that, prior to this experience, they saw research as intimidating, believed that they were not smart or creative enough to do research, and had positively changed their perception of research and their ability to do it through the course experience. The sentiment about research being intimidating was missing from the Dartmouth focus groups and likely reflects a real difference in prior student experience between the two courses: on precourse surveys, 12 of 13 Dartmouth students reported some prior research experience, whereas only 3 of 8 Elon students reported any prior research experience. Differences between the cohorts also likely reflected differences in course prerequisites and application procedures: the Dartmouth course required more prerequisite ecology knowledge and had a more competitive application process than did the Elon course.

Differences between courses also likely reflect differences in course durations and the number of research projects conducted by students: indeed, it would be surprising if student learning and developmental gains did not differ. For example, Dartmouth students had seven iterated small-group UREs of their own design and nine weeks to work on projects. Key themes in Dartmouth focus groups included student enthusiasm for conducting research of their own design. These comments are also consistent with responses on the CURE survey: all of the Dartmouth students gave the highest possible score for working on a project of their own design. Interestingly, the Dartmouth students also reported lower perceived gains in learning to work independently compared to the average CURE survey score, likely because they always worked in groups with other students, despite their autonomy to decide about research projects. In contrast, the brief duration of the CURE module in the Elon course limited developmental opportunities associated with longer research experiences such as progressive development of autonomy (Shanahan et al. 2015), and the CURE module was the only portion of the Elon course during which students designed their own research activity. Elon students made fewer comments than the Dartmouth students overall about working on projects of their own design.

Although students in both courses noted that their interactions with host-country individuals were limited, this comment was more frequent among Dartmouth students. Dartmouth students mentioned their efforts to speak Spanish and interact with local guides and field-site personnel, but Elon students made more comments about interacting with Panamanians and spoke about some topics not mentioned by Dartmouth students, including the dynamics in host-country homes and the closeness of the families they observed. This difference between courses is unsurprising, as Elon students participated in homestays, but Dartmouth students did not do so. Homestays appeared to affect Elon student perceptions strongly and positively and may have encouraged them to continue seeking interactions with host-country individuals in subsequent modules.

Suggestions for Improving Outcomes in Undergraduate Research Study Abroad Experiences

Designing courses with two high-impact practices requires consideration of how the design of each high-impact practice may constrain or interact with the other and effects on student learning. For example, STSA courses vary widely in duration (Institute of International Education 2019) and the degree of travel among sites versus cultural immersion within sites (Bender et al. 2017). These course elements are likely to strongly influence student development in intercultural competence, but they should also affect student learning about research, because the duration, type, and number of UREs affect student learning (Linn et al. 2015). Similarly, the consequences of cohorting are interesting to consider from both the research and study abroad perspectives. From the research perspective, that students in traveling cohorts developed strong community with each other is an advantageous by-product of the study abroad format. Building a sense of community among student researchers is recognized as a mentoring practice that promotes student learning and development, but faculty mentors report that this goal can be difficult to achieve in traditional research contexts (Shanahan et al. 2015). From the study abroad perspective, the comments from students in both courses seem to support findings by Bender and colleagues (2009), who showed that students in cohorted UREs interacted less frequently with host-country nationals and immersed less deeply in host-country culture than did individual students embedded in host-country research groups. It is suggested that course instructors carefully consider structural elements of courses that can impact student learning.

Course goals and activities should also consider the focal student population. What students learn from a particular program design will be influenced by their pre-existing knowledge, development, and experience. For example, in a study that compared learning gains about research among students enrolled in two international and one domestic program, Bender and colleagues (2009) found that students new to research reported greater gains than did more experienced students: self-reported learning gains differed among the less- and more-experienced students in understanding the research process, the role of scientists in working on real problems, and the ways in which scientists think.

Finally, student reflections during and after the courses were valuable and informative for student learning and also for reflection about future iterations of the courses. For example, some perceived benefits of the courses differed from student predictions in precourse surveys. Although students in both courses ranked opportunity to practice language among the lowest reasons for taking the course, students in both courses commented in written reflections that they appreciated the opportunity to practice and develop their language skills. Similarly, some experiences were not appreciated by students as they were occurring but were strongly valued after the courses ended; during focus groups, some Elon students discussed their appreciation of rigorous field experiences after the course ended but not while they were in progress.

Recommendations for Future Research on Combining Undergraduate Research with Study Abroad

In this study, students reported some gains that are unique to a combined research-study abroad experience. Validated tools exist for separately assessing learning gains from undergraduate research and from study abroad, but to the authors' knowledge, there are not yet validated tools for assessing student learning during this kind of combined experience. Evaluating student gains derived from intersecting high-impact practices, as well as evaluating student learning in each area when research and study abroad simultaneously occur, should be a priority.

Conclusions

The benefits of undergraduate research and study abroad for students have been well studied separately (Kuh 2008; Linn et al. 2015; Vande Berg, Paige, and Lou 2012). Combining undergraduate research with study abroad can encourage more students in STEM majors to participate in study abroad courses (Bender et al. 2017) and encourage more students in non-STEM majors to engage in undergraduate research (Banks and Gutiérrez 2017). For institutions interested in exploring undergraduate research in international contexts, embedding UREs within STSA courses is a model that promotes broad access: it avoids some of the financial barriers associated with international one-on-one mentored UREs that could impede student access and provides international research opportunities for students who are not yet prepared for the challenge of an independent, international research experience.

The findings suggest that students in both courses derived some unique benefits associated with engaging in undergraduate research in an international context, despite many differences between the courses. There appear to be both tradeoffs and synergistic effects associated with how course elements affect student learning from each high-impact practice, providing fertile ground for future research.

Acknowledgments

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Jennifer A. Hamel
Elon University, jhamel2@elon.edu

Jennifer A. Hamel, an associate professor in the Department of Biology at Elon University, teaches undergraduate courses in biodiversity, ecology and evolution, animal behavior, and field ecology. Her primary research focus is investigating how interactions between species shape behavior, particularly communication. She also studies how high-impact practices such as research experiences influence student learning.

Hannah M. ter Hofstede—an associate professor in the Department of Biological Sciences and Graduate Program in Ecology, Evolution, Ecosystems and Society at Dartmouth College—teaches undergraduate courses in physiology, animal communication, and field ecology. Using physiological, behavioral, ecological, and evolutionary data, she investigates how animals use sensory information to make decisions affecting survival and reproduction.

Adrienne Gauthier, learning designer at Dartmouth College, collaborates with faculty on creating learner-centered environments in the classroom and assessing the impact of instructional strategies on the student experience.

David Lopatto is a professor and director of Center for Teaching, Learning, and Assessment at Grinnell College. Much of his research focuses on assessing the impacts of undergraduate research experiences. He has designed several survey instruments that capture student self-reported gains in knowledge, skills, and confidence in research.

Prudence Merton, lecturer in arts and sciences at Dartmouth College, collaborates with faculty on developing pedagogies, assessments, and curricula, as well as assessing their impacts on student learning.

David Vandermast is an associate professor in the Department of Biology at Elon University. His research interests include plant ecology, conservation, and teaching and learning in study abroad courses.

INTERNATIONAL PERSPECTIVES

Re-evaluating Passive Research Involvement in the Undergraduate Curriculum

Nicholas Grindle, Stefanie Anyadi, *University College London*
Amanda Cain, Alastair McClelland, *University College London*
Paul Northrop, Rebecca Payne, *University College London*
Sara Wingate Gray, *University College London*

Abstract

In recent years, advocates for research-based education have publicized many examples of passive research involvement, defined as undergraduates learning about the content and lived experience of research at their institution. But the qualitative dimensions of passive research involvement remain unknown. The authors' study uses Diana Laurillard's "conversational framework" to analyze reports from 367 undergraduate students at a UK research-intensive university who met researchers and learned about their work. The results show a range of experiences in student learning about faculty research. These findings make the case that passive research involvement has its own integrity and cannot be characterized as an absence of participation. The authors suggest ways that the students as audience category can enhance undergraduate connections with research.

Keywords: *early undergraduate research, first-year curriculum, research-based education, research-teaching nexus*

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This article analyzes passive research involvement in the learning activity Meet the Researcher. In Meet the Researcher, undergraduate students work in groups to find out about the work of an individual researcher in their department. The content of the activity varies but always includes at least one of the following: searching for information online, reading the researcher's work, visiting the researcher's workplace, and interviewing the researcher. Students share their findings in a presentation or a written report. Taking part in the activity helps students learn about their instructors' research activity, and some students have said it helps them discover areas of study they would like to pursue further. For faculty in the United States, it offers a lower-cost and more democratic access to the lived experience of faculty research than undergraduate research experiences and undergraduate research opportunities programs. Geographers Denis Cosgrove and Claire Dwyer first described the activity and Mick Healey promoted it to show linkages between research and teaching (Cosgrove 1981; Dwyer 2001; Healey 2005). Universities keen to put education on an equal footing with research have featured Meet the Researcher activities in their institutional pedagogies (Fung 2017).

One clear problem in recent discussions of Meet the Researcher is that the language of research-based education has no means of describing passive research involvement on its own terms. Healey (2005) referred to Meet the Researcher in a context where he compared "students as audience" unfavorably to "students as participants." As Mary Malcolm pointed out, "Healey's 'student as audience' categories are those in which no student role is specified and there is therefore no clear pedagogical position rather, than arising from a distinction created within the model" (Malcolm 2014, 293). Didi Griffioen (2019) has echoed Malcolm's observation, calling for more precise definitions of research involvement and "passive" research involvement in particular.

This study clarifies what happens in passive research involvement by analyzing students' reports about their participation in Meet the Researcher. The warrant for seeking student perceptions comes from recent work showing that students' awareness of researchers and their work is distinct from their awareness of their participation (Visser-Wijnveen, van der Rijst, and van Driel 2016). Diana Laurillard makes this distinction when she argues that formal education differs from experiences of the world because students learn about "the complex and alien facts and ideas coming from the minds of others" (Laurillard 2013, 50) in formal education (such as that occurring at a university) rather than learning about the world directly. Laurillard identifies six ways that students learn in formal settings:

- *acquisition* ("this is what learners are doing when they are listening to a lecture or podcast, reading from books or websites, and watching demos or videos," 105);
- *inquiry* (where students make "use of resources that provide searchable access to information, data, knowledge, and ideas" and begin to "turn the teacher's narrative into their own," 122);
- *peer discussion* (where the learner takes "a particular position with respect to a concept" and engages in a cycle of communication with their peers with a view to working "towards an agreed output," 160);
- *practice* (where the student works independently of the teacher "to apply their understanding of the concepts to achieving a task goal" [162] in an exercise prepared by the instructor);
- *production* (where "the teacher motivates the learner to consolidate what they have learned by articulating their current conceptual understanding and how they used it in practice," 98);
- *collaboration* (which is "about 'creating joint reference', something the learners make together, and then use to move on to further exploration," 142).

These learning types each represent "how the learner experiences the types of learning" (99).

Using Laurillard's typology, this article analyzes responses from 367 undergraduate students at a large UK research-intensive university to a single question about their experience of Meet the Researcher. The findings offer a more precise definition of passive research involvement. By specifying a role for students in Meet the Researcher and establishing its range of qualitative variation, it is possible to argue that passive research involvement has a value that is overlooked by influential models of the relationship between research and teaching. The article concludes by outlining possibilities for the *students as audience* category in enhancing student relationships with research.

Methods

Understanding the *student as audience* category requires an examination of students' experiences of passive research involvement. Phenomenography—a successful line of inquiry in recent studies of the teaching-research nexus, according to Malcolm Tight (2016)—provided a useful method in assessing student descriptions of the task of engagement with the researcher so that their experience could be better understood. Categories from Laurillard's conversational framework, which is also significantly influenced by phenomenography, assisted in analyzing the internal relations of those descriptions (Laurillard 2002, 2013). The researchers did not test *what* the students learned, nor documented the impact of this particular activity.

A note on terminology may be helpful here. *Task* is used to refer to a component of Meet the Researcher such as interviewing the researcher, and *activity* refers to Meet the Researcher as a sequence of related tasks that compose a single large activity. *Module* is used instead of *course* to refer to a unit of learning that forms part of a student's degree program.

For this study, the lead researcher contacted representatives of seven degree programs in the university that conduct Meet the Researcher activities. One declined to take part in the study, so students from six programs participated. The programs and their associated Meet the Researcher activities are here identified by initial letters enclosed by parentheses. They include the faculties of life sciences (LS); arts and humanities (AHE); brain sciences (BS1) and (BS2), which are different programs in different departments within the same faculty; architecture and the built environment (ABE); and mathematical and physical sciences (MPS). Some of these programs feature in recent scholarship: Fung (2017) has discussed life sciences; Anyadi (2016) has described brain sciences 1; two recent case studies have focused on brain sciences 2 (Fung 2016; Evans et al. 2018); and mathematics and physical sciences have been analyzed recently (Grindle, Jones, and Northrop 2020).

Students were asked via a single open question to describe their experience of taking part in Meet the Researcher. A single question was chosen because it was thought unlikely that students would answer more than one question due to time constraints. Also, early responses showed that a single open question was sufficient for the study's purpose, which was to identify variation in descriptions of passive research involvement against predefined criteria. The question was the following: "Say you are meeting up with a friend following the 'Meet the Researcher' activity. What would you tell them [sic] about it? Feel free to mention anything at all, for example what you learned, what you enjoyed or didn't enjoy, what was easy or hard, what

TABLE 1. Comparison of Key Contextual and Descriptive Elements in Each Activity

	Life sciences	Arts and humanities	Brain sciences 1	Brain sciences 2	Mathematics and physical sciences
Activity duration	up to 5 weeks, at the start of term 1	10 weeks, in term 2	4 weeks, at the start of term 1	3 weeks, early in term 1	5 weeks, in the second part of term 1
Part of a course?	No	Yes	No	No	Yes
No. of students in group	5	between 4 and 5	5	between 6 and 8	6
Output	Discussion in tutor group (researcher + 5–6 students)	1500-word report (individual), video diary (group)	Group presentation to all students (n = < 35) and researchers (n = < 8)	Group presentation to other half of tutor group (4–5 students)	Short, written summary of research paper
Output carries marks for credit?	No	Yes	No	No	Yes

was well organized or wasn't, or anything else." The question included example responses to indicate that students could report their thoughts, feelings, or any other aspects of their experience.

Female module leaders with PhDs administered the question in LS and AH, and a male module leader with a PhD administered the question in MPS. Experienced female teaching managers who do not teach or hold PhDs administered the question in BS1 and ABE, and the male professor who is program leader for BS2 administered the question in his program. In all cases, the person administering the question also designed and operated the Meet the Researcher activity in their respective program, and in all cases the students knew the person administering the question. These staff members all completed a short questionnaire about their respective activity. Table 1 summarizes the main points about each iteration of Meet the Researcher.

The distribution method of the question meant it was easier to reach the entire population (a total of 575 undergraduate students, of whom 538 were first-year undergraduate students and 37 were second-year undergraduates) than to conduct a sampling process. Methods for gathering the data differed. In all cases except MPS, the people administering the question did so by email within four weeks of the activity taking place, and the students enclosed a response in their replies. In MPS, the module leader used an optional question that appeared before students submitted their coursework assignment via the university's virtual learning platform in the week that the activity finished. In all cases, the people administering the question anonymized the responses before passing them to the lead researcher. When analyzing the data, the researchers used the context reported by the student as a guide to whether the student's activity corresponded to those from Laurillard's framework. The lead researcher coded the data using NVivo software, and a second researcher used random sampling to verify the coding. The project used the UCL Teaching and Learning Centre's blanket ethics clearance for small-scale educational projects.

Unfortunately, students from ABE reported their answers in a way that made it impossible to isolate individual responses. They also failed to complete the activity, which was optional and not part of a credit-bearing module. Their responses were excluded from the results (this is discussed further in the Limitations section).

Results

The number of respondents to the question was 367, with the following response rates:

- LS, n = 50, a response rate of 44.6 percent
- AH, n = 47, a response rate of 41.9 percent
- BS1, n = 10, a response rate of 16.1 percent
- BS2, n = 47, a response rate of 42.0 percent
- MPS, n = 213, a response rate of 91.4 percent

Table 2 shows how students reported their experience of Meet the Researcher, using Laurillard's six learning types. In many cases, multiple categories in a student's report could be identified. To better highlight the distribution of reports, each dimension is shown in parentheses as a percentage of the total student comments from each group.

The most frequently mentioned aspect of students' experience was *inquiry*, where students investigate resources identified by the instructor. It accounted for more than one-third of all comments relating to student activity and was the most frequent report in three of the five programs. The *acquisition* of concepts from the instructor accounted for a quarter of all student comments about their experience. *Practice*, where students applied their understanding of the concepts in an exercise prepared by the instructor, rarely featured in student comments, except in AH, which explicitly set out to provide students with the opportunity

TABLE 2. Student Reports About Their Experience of Meet the Researcher

	Life sciences (*n* = 50)	Arts and humanities (*n* = 47)	Brain sciences 1 (*n* = 10)	Brain sciences 2 (*n* = 47)	Mathematics and physical sciences (*n* = 213)	Total
A. Acquisition	27 (47%)	17 (24%)	1 (8%)	9 (19%)	82 (23%)	136 (25%)
B. Inquiry	25 (43%)	14 (20%)	5 (42%)	24 (50%)	123 (35%)	191 (35%)
C. Discussion	0 (0%)	3 (4%)	0 (0%)	1 (2%)	23 (7%)	27 (5%)
D. Practice	2 (3%)	21 (30%)	0 (0%)	1 (2%)	2 (1%)	26 (5%)
E. Collaboration	0 (0%)	11 (16%)	2 (17%)	5 (10%)	75 (21%)	93 (17%)
F. Production	4 (7%)	4 (6%)	4 (33%)	8 (17%)	48 (13%)	68 (13%)
Total	58 (100%)	70 (100%)	12 (100%)	48 (100%)	353 (100%)	541 (100%)

Note: The number of reports is itemized against the learning activities in Laurillard's conversational framework and expressed in parentheses as a percentage of all student comments from each group.

for putting theory into practice. Students rarely mentioned *production*, apart from those in BS1 who presented their work in a lively and informal lunchtime session.

Discussion and *collaboration* are about the interactions of students with their peers rather than with the instructor (which, in this context, features as *inquiry*). Students reported discussion when talking about their interview with the researcher, but this has been classed as *inquiry*. When students reported discussion between peers, it was almost always in the context of *collaboration*, which is a category that encompasses peer discussion. Laurillard defines *collaboration* as cycles of inquiry and action to generate concepts and practice, which is modulated via cycles of discussion and practice with peers. *Collaboration* itself was the third most common factor mentioned overall.

Taken by group, the results offer a varied picture. In LS, the students learned as the researcher explained key concepts and demonstrated actions, and they also investigated online resources. Discussion and collaboration rarely featured in their reports. A similar picture emerges in BS2, although, in this case, the students investigated resources, and this shaped their experience more than absorbing concepts explained by their professor. Only a few students in BS2 reported interacting with their peers. Student reports from BS1 show that investigating the resources made available to them for the activity significantly shaped their experience. This group also provided the lowest score for *acquisition* and the highest score for *production*. The small number of responses from BS1 is likely because the question was given to the students some weeks after the activity took place.

Students' experiences in MPS and AH differ from the other programs because they are more evenly distributed across Laurillard's learning types. The low *inquiry* score for AH is explained by the high *practice* score. Both types of learning focus on investigation, but *practice* is practical rather than conceptual and repeated in cycles. Students in MPS reported a similarly even spread of learning types, albeit with a slightly higher emphasis on *inquiry*, *collaboration*, and *production*, with *practice* barely registering at all.

Discussion

The results show that student experiences of Meet the Researcher vary widely. In all but one group (AH), a clear majority of students report their experience in terms of *acquisition*, *inquiry*, and *production*, which are all forms of one-way communication. (In AH, the figure for these elements of the students' experience is 50 percent). In addition, 30 percent of students in AH report their experience in terms of *practice*, and 21 percent of respondents from MPS report their experience under the *collaboration* category. Actions involving repeated cycles of conversation with peers are more closely associated with higher-order outcomes than tasks with fewer opportunities for exchange (Laurillard 2013). Students in AH and MPS must also do more things and spend more time on the task than students in LS, BS1, and BS2. These are also factors associated with stronger learning (Gibbs and Simpson 2004). Meet the Researcher as a whole requires students to learn about someone else's research, and some forms of the activity clearly afford students the scope to achieve higher-order learning outcomes.

AH and MPS differ from other programs in that these faculties require written outputs from the participants in Meet the Researcher, which the module leaders grade for credit. Fung (2017) emphasizes that Meet the Researcher activities give students an opportunity to present their findings and develop communication skills. But, in the results reported here, there is no association between *production* and higher-level outcomes. In fact, the opposite is true. MPS students are more likely to report *collaboration* than *production* as an element of their experience. The contrast is sharper in AH, where *production* is the least frequently mentioned category, together with *discussion*. Although the finished output may determine how students distribute their effort, there is no evidence that it shapes their perceptions of what they are doing. In AH and MPS, students need to collaborate to make sense of what researchers have said (in interviews, via coding; or in research outputs, via reading and preparing for an interview). Problem-solving is more prominent in these iterations of Meet the Researcher than it is in LS, BS1, and BS2, where students investigate the researcher themselves, rather than the researcher's thinking as manifested in words and artifacts.

Through analyzing student experiences of Meet the Researcher, it is possible to better understand what students are doing when they learn about the work and activity of researchers in their program. Therefore, it can be claimed that passive research involvement is a pedagogical position in its own right. As Malcolm (2014) noted, frameworks modeling the relationship between teaching and research tend to figure passive research involvement as the absence of participation in research activities. The findings show that this is not the case. Passive research involvement has its own integrity: it comes in different forms and can be modified for different purposes. Furthermore, recent literature showcases Meet the Researcher activities on the grounds that it helps connect students with researchers and their work as well as makes a good first step in a wider program of turning students into researchers. With a clearer understanding of what students experience when they engage with research produced by staff, the intrinsically distinct and desirable outcomes of passive research involvement can be recognized. The following section describes some ways to develop this activity so that students can engage with faculty and staff research in increasingly sophisticated ways through the later years of undergraduate programs.

Practical Implications

Two possibilities follow from the claim that students learning about researchers and their work (what is termed here *passive research involvement*) is a meaningful activity in its own right. First, these activities need to be developed and extended, rather than led by a teleology that prioritizes students' participation in research activity. Meet the Researcher can be used in all years of undergraduate study to connect different elements of a degree program and help students foster their own understanding of research. Students can also use interviews to interrogate and demystify core academic skills such as the capacity to engage productively with feedback (Marie et al. 2019). Whatever the focus, there is opportunity for students to foster their own development by learning together with experts.

Second, the pedagogical virtues of passive research involvement can shed a more positive light on the early years of postsecondary education. The work here shows that students engage meaningfully with researchers and their work from the very start of their time at college. Passive research involvement also fosters meaningful relationships between new students and researchers. Recent research shows that students in the early stages of their degree have a poor understanding of the research process (Bage 2019; Brooks et al. 2019; Clark and Hordosy 2019). This work measures student awareness in the context of a three-year curriculum that culminates in a final-year project or dissertation. Such a trajectory will invariably show first-year conceptions to be unsatisfactory and incomplete. Rather than striving for students to conduct research so that the early postsecondary years match the later years, it should be acknowledged that high-level outcomes are possible when students learn about research from researchers and that this can be achieved in the earliest stages of undergraduate study. There is every reason to extend these activities into the later years of study while bringing more active research participation into the earlier years of the curriculum.

Limitations

A number of limitations exist. First, the question given to the students included examples of possible responses, which might have influenced students' responses. Indicating the range of possible answers would encourage a wider range of responses, but it may be the case that students failed to mention certain learning types as a result of the question that was asked. Second, in the LS, AH, and MPS programs, the question was administered by a staff member who was also involved in assessing the students' work. This may have influenced the students' responses. Third, the question had a response rate lower than 50 percent in four of the five programs included in the results. It is possible that the participants are students identifying some specific learning types. Fourth, the sequence of student experiences was not captured, which makes it difficult to evaluate the effect of module design on student experiences or to share and refine these designs—a key point in Laurillard's work. This is a possible area for future study. Finally, it is unclear why the 31 ABE students failed to complete the activity. The tasks of investigating and interviewing the researcher may have appealed more than producing a poster summarizing the key findings from the interview.

Conclusion

Using reports from 367 undergraduate students at a UK research-intensive university, this article has responded to recent research noting the vagueness of the term *passive research involvement* by defining what occurs when first-year undergraduate students engage with the work of researchers. A framework of formal learning to evaluate student experiences of Meet the Researcher activities revealed a striking qualitative variation in student experiences. It seems that passive research involvement is not so passive after all. These results can provide a better picture of the early years of postsecondary education and show how students might engage with researchers and the institution's research in increasingly complex and challenging ways through all their years of study.

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Nicholas Grindle

University College London, n.grindle@ucl.ac.uk

Nicholas Grindle is lecturer (teaching) in UCL's Arena Centre for Research-Based Education, investigating how faculty's experience of research can be used to improve student learning.

Stefanie Anyadi is teaching and learning team manager in the UCL Division of Psychology and Language Sciences, and previously served as faculty academic administration manager in the UCL Mathematics and Physical Sciences Faculty Office.

Amanda Cain is associate professor (teaching) in the UCL Division of Biosciences. She earned her PhD from UCL.

Alastair McClelland is professor of behavioral statistics in the UCL Division of Psychology and Language Sciences and *director of studies for the undergraduate program in psychology. Author of more than 86 publications in experimental psychology and pedagogy, he is interested in developing novel methods to assess and improve student understanding of assessment literacy and feedback, and more generally in enhancing the undergraduate student experience.*

Paul Northrop is associate professor in the UCL Department of Statistical Science. He earned a PhD in statistics from UCL and conducted postdoctoral work at UCL and Imperial College. He was a departmental lecturer in the University of Oxford's Department of Statistics from 1999 to 2005.

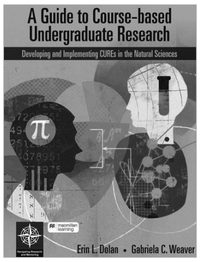
Rebecca Payne is student experience officer in The Bartlett, UCL Faculty of the Built Environment, where she leads several projects and initiatives that serve to enhance the student experience, especially at the undergraduate level.

Sara Wingate Gray is lecturer (teaching) in UCL's Department of Arts and Sciences. Her research focuses on public libraries, the philosophy of librarianship, digitization, ephemera, and special collections. She previously was a visiting research scholar at San Francisco State University, working with the Poetry Center and American Poetry Archives.

Book Review

A Guide to Course-Based Undergraduate Research: Developing and Implementing CUREs in the Natural Sciences

Erin L. Dolan and Gabriela C. Weaver



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Reviewed by Gita Bangera, Bellevue College, gita.bangera@bellevuecollege.edu

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Erin L. Dolan (University of Georgia) and Gabriela C. Weaver (University of Massachusetts Amherst) have set out on an ambitious venture to create a comprehensive guide to course-based undergraduate research experiences (CUREs) in the natural sciences. Their goal is to support faculty, and to some extent administrators, who would like to develop and implement CUREs as a pedagogical tool in higher education.

In the foreword, Jay Labov (retired, National Academies of Science, Engineering, and Medicine) quotes John Dewey (1910, 122) on the importance of teaching science "as a method of thinking, [and] an attitude of mind." Labov also highlights the need to make research experiences a right—equitably accessible to all undergraduates. Indeed, CUREs are a way to accomplish both these goals. However, developing and implementing a CURE in a single class can be a daunting experience, not to mention scaling-up across disciplines. Having a practical "how-to" guide like this book can make all the difference.

This book is well-structured. It starts with the why, what, and the how of developing and implementing CUREs and then addresses the broader issues of institutionalization and scaling-up. The final chapter addresses the scholarship of teaching and learning that inspires CUREs—in this instance, specifically in the context of discipline-based research on pedagogy. The authors have done an excellent job of thinking about the need to transition the student from a novice to an expert with the section on intellectual translation and cultural translation. The authors' vision of the student as the scholar side-by-side with the faculty member is truly to be applauded.

The appendices could be invaluable to a practitioner starting in the world of CUREs. They provide enough structure to make the process less intimidating and are flexible enough to encourage experimentation and innovation. The timely appendix 3, "The Contingency Plan for CURE Instruction," highlights one valuable lesson learned as the world reels from a pandemic that severely restricted in-person teaching and research. These tools will be a great, repeat-use resource for bringing CUREs into an increasing number of online STEM courses.

The book is written in an engaging style that is approachable for novices and experts alike with useful callouts about lingo (to explain theoretical terms or technical jargon), tips (to highlight useful tools and ideas), and equity (to draw attention to equity-generating practices). The consistent emphasis on equity in the context of CUREs is one highlight of the book.

For the faculty member learning to develop and implement CUREs, the book provides not only a strong theoretical framework but also step-by-step support with backward-design protocols and worksheets. By the same token, for the faculty member navigating the uncharted waters of institutionalization and scaling-up, the authors also provide great strategies such a "empathic dialogue" with deans and other administrators within the institution.

The authors state that this book is aimed at anyone who wants to implement CUREs. However, it seems to be more focused on addressing the needs of faculty at research universities and does not offer enough for those at other types of institutions. Almost half of undergraduate students start their education at community colleges, and that number is even higher for students from minoritized populations and first-generation college students. The impact of this book could be broadened by the inclusion of tools and strategies, for example, aimed specifically at community college faculty. There are, after all, many examples of community college faculty who have developed and implemented CUREs. These practitioners have developed strategies needed to support students who may have less confidence in themselves as researchers and be reluctant to identify themselves as scientists. Future editions of this book would benefit from including examples of these strategies and more, as they are critical to faculty at all educational institutions who are interested in democratizing access to STEM research experiences.

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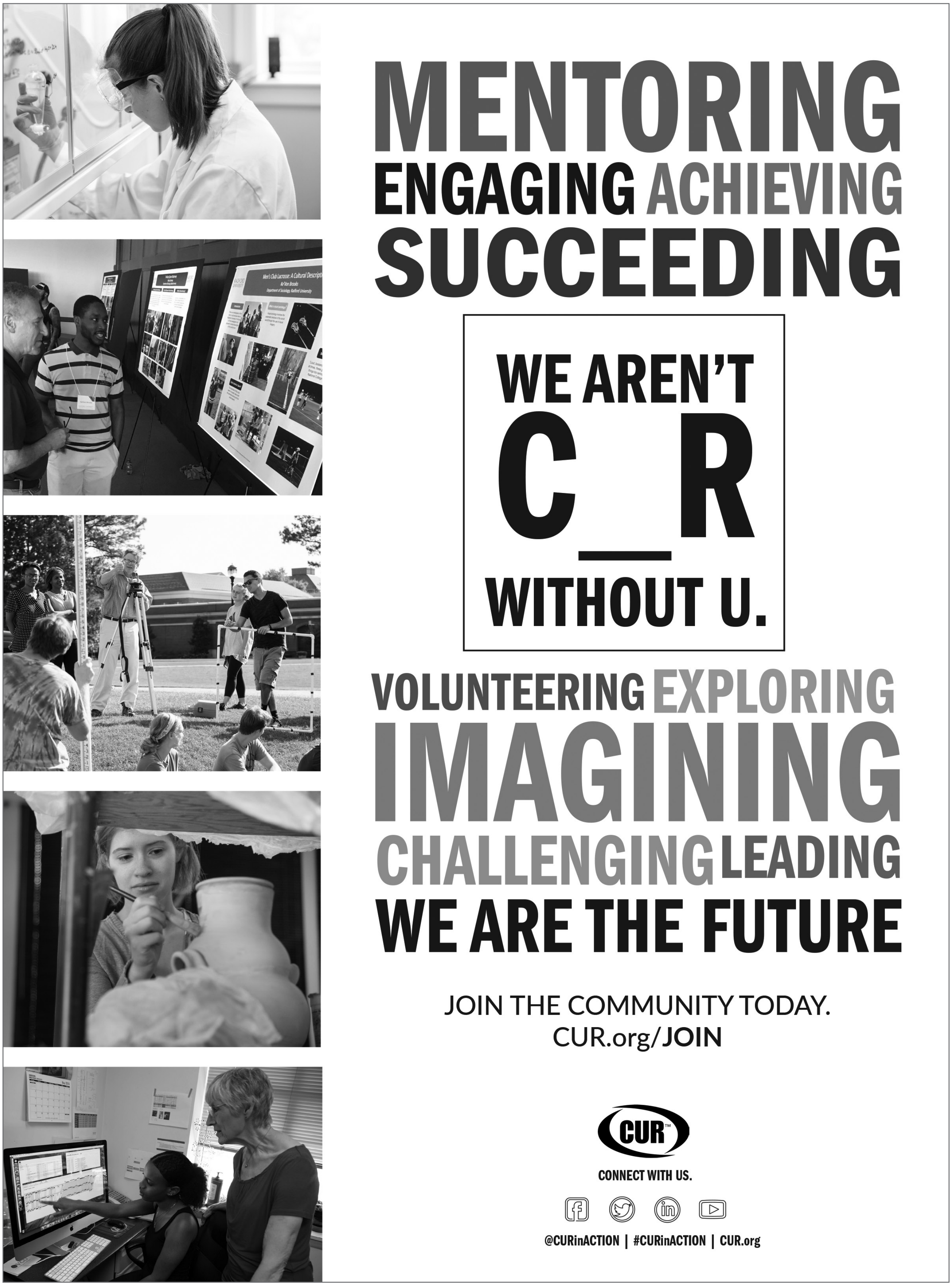
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The Journal of the Council on Undergraduate Research

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Patricia Ann Mabrouk
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p.mabrouk@northeastern.edu