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UNDERGRADUATE RESEARCH COLLABORATIONS: PARTNERING FOR HIGH(ER) IMPACT

Also in this issue:

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Development of a Client-Based Undergraduate Molecular Biology Laboratory

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CUR Focus

Collaborative Research Networks Provide Unique Opportunities for Faculty and Student Researchers

Abstract

We discuss the benefits that a collaborative research network, a group of faculty from different institutions who jointly conduct a research project, can have on undergraduate research (UR) by enhancing the diversity and significance of projects and by improving student motivation and breadth of learning. The main example used is the Ecological Research as Education Network (EREN), founded in 2010 to enhance undergraduate research in ecology at primarily undergraduate institutions (PUIs) by (1) providing networking and collaborative research opportunities for both faculty and students and (2) developing free educational resources. EREN comprises about 280 ecology faculty and staff nationally and has facilitated development of nine continental-scale, collaborative research projects.

Project leaders design a research project that can be conducted by faculty and students at just about any college. Faculty and their students carry out the data collection at their home institution and submit it to the publicly available project database. Then participants (and even non-participants) can avail themselves of the large, multi-year, continent-wide data set. Substantial benefits have been reported for programs, faculty, and students. Undergraduate research programs are broadened and faculty benefit because they gain insights and laboratory techniques from colleagues in other institutions and fields, thereby expanding the diversity of potential undergraduate research projects and resulting in more broadly trained undergraduates. The research projects themselves have become educational resources incorporated into courses at all levels, as well as independent research projects. Because data collection happens nationwide, college faculty and students at small colleges are now able to investigate large-scale ecological questions.

Preliminary assessments have shown significant improvements for some student-learning outcomes, including thinking across scales, use of best practices in data management, and describing scientific collaboration techniques. Students demonstrate increased motivation and retention through participation in a nationwide, authentic research project with publication-quality data, becoming part of a community of scholars and gaining a sense of belonging and responsibility. Despite challenges with coordination and communication, students are exposed to a wider range of techniques and subfields of ecology than they would be without this network.

In the TurtlePop project, students and faculty from institutions across the U.S. collect data on local turtle populations and upload them to a central database. Pictured here is Dr. Jodi Yorty (right) and two students from Elizabethtown College.

Introduction

Scientific research in the 21st century increasingly is a collaborative effort (Craine et al. 2007; Penman and Goldson 2015). Undergraduate research, however, is still mostly confined to projects within a single institution. For example, of the 24 studies listed in the Undergraduate Research Highlights of the *CUR Quarterly* in the summer and fall 2015 issues, only eight were collaborative efforts by authors at multiple institutions. We argue that undergraduates' participation in inter-institutional collaborative research will better prepare students for modern scientific careers and provide them a greater diversity of research experiences. Students could learn a great deal by working in a successful scientific collaboration. Although many professors require students to work on research projects in groups, few model this approach for students by collaborating themselves with faculty peers on these projects.

Faculty as well as students benefit from inter-institutional collaborative research, especially at primarily undergraduate institutions (PUI) where faculty have less time and fewer resources to devote to their research programs than faculty at research universities (Kaplan 2011). Faculty members at PUIs tend to have heavier teaching loads, greater responsibilities for academic advising and other types of service, and fewer disciplinary colleagues than faculty at research institutions. Scholarship in the form of publications is expected at most PUIs, although requirements tend to be more modest than at research institutions. At the same time, expectations that undergraduates will be incorporated into faculty research programs have been increasing. Research at PUIs thus has dual goals: It is a means to advance one's personal scholarship and to provide high-quality learning opportunities for undergraduates. Collaboration among faculty members from different institutions can be key to achieving both of these goals. We use the Ecological Research as Education Network (EREN) as a successful case study of implementation of faculty-student collaborative research across multiple undergraduate institutions.

Description of EREN

Now in its seventh year, EREN is funded by the National Science Foundation's (NSF) Research Coordination Networks-Undergraduate Biology Education Program (Award No. DBI-0955344). Created in 2010 by a team of faculty from 14 undergraduate institutions, EREN's mission is to build a network in which faculty can create and test models for collaborative, large-scale ecological research projects involving undergraduates that explore important scientific questions and have genuine potential for publication in peer-reviewed literature (http://erenweb.org; Bowne et al. 2011). Multi-site, collaborative research is currently an important focus for the ecological community; the NSF-funded National Ecological Observatory Network (NEON) is an example (Goodman et al. 2015). As of February 2016, EREN's membership included 278 faculty and staff representing 210 institutions in 41 U.S. states, Puerto Rico, Canada, Scotland, the Bahamas, Colombia, Mexico and Singapore. These members bring a wide range of terrestrial and aquatic expertise to the network and include individuals interested in almost every aspect of ecology and ecological education.

EREN members are invited to propose research projects that are scientifically interesting, collaborative across sites and institutions, appropriate for undergraduate participation, and feasible for institutions with limited resources for research. EREN facilitates online communication among these "lead scientists" and network members. Individual faculty members then volunteer to become collaborators in the research and engage their students in data collection, sharing, and analysis. Participants upload their data to a common database or send them to the lead scientist who summarizes and shares the data set. Projects can lead to published manuscripts (e.g., Simmons et al. 2014) and conference presentations, but most participating faculty use them primarily as laboratory and lecture activities in undergraduate courses.

Sonja Helgeson, a student at St. Olaf College in Northfield, Minnesota, measures tree diameter as part of an inter-institutional collaborative research project.

According to an internal accounting, more than 4,000 students have utilized EREN research or data in courses, independent study projects, and summer research experiences. EREN sponsors an annual meeting at which project ideas, research protocols, pedagogical strategies, and data can be discussed and where working groups can gather to further individual projects and manuscripts. Currently, EREN has eight active projects that span the range of ecological subdisciplines. Topics include decomposition rates of invasive plants, spread of invasive earthworms, bird-window collision patterns, and forest community dynamics, among others.

The project titled Population Structure of Freshwater Turtles along an Urbanization Gradient (TurtlePop) will serve as an illustration. David Bowne conceived the project as an expansion of the turtle research in which he was engaging undergraduates at Elizabethtown College. EREN members from a wide diversity of ecological subfields were intrigued by the potential of the project, despite their inexperience in herpetology. They jumped at the chance to expand their expertise and were trained by Bowne in turtle handling, trapping, and identification through hands-on sessions at EREN-sponsored meetings, at the annual conference of the Ecological Society of America, via instructional videos (https://www.youtube.com/channel/UCRJ_o8zzZg9vhRSa8kDiEzA), and through visits to Elizabethtown College.

Faculty researchers found that this training, coupled with detailed written protocols and a classroom curriculum (http://www.erenweb.org), enabled them to incorporate TurtlePop into introductory and advanced undergraduate courses, thereby engaging hundreds of undergraduates in a new and exciting national study of wildlife that normally would not be available at PUIs. Several participants have used TurtlePop

as a springboard to develop additional projects or collaborations with community members and faculty at neighboring institutions. A core group of 26 TurtlePop faculty researchers are currently working on a manuscript to publish their scientific findings.

To gauge the success of EREN at the five-year mark, an online survey of members was developed by the leadership team that focused primarily on the perceived benefits of EREN for faculty. The 31-question survey was distributed to 313 EREN members in September 2015 with a 10-day response period. This short response time is probably the main reason for the low response rate (47 respondents, a 15-percent response rate). The respondents provided descriptive information, such as gender, but did not reveal their identities. A network-wide assessment of student learning is currently underway.

St. Olaf College students Nora Flynn and Ellen Squires collect leaf decomposition bags from a stream near their campus in Northfield, Minnesota.

Collaborative Network Benefits for Faculty

Collaborative efforts such as EREN offer peer mentoring, research, and pedagogical benefits to faculty. According to the EREN survey, 94 percent of respondents "agreed" or "strongly agreed" with the statement, "EREN improved my network of professional contacts" (Table 1). At their best, these networks may foster transformational research and professional development that facilitates lifelong learning. Yet even before such lofty goals are realized, collaborative networks offer valuable faculty support. Many PUI faculty start their careers with relatively little understanding of what their jobs entail. The training they receive in graduate school focuses on research, but teaching is important at all PUIs. In addition, at small institutions a faculty member may be the only representative of his or her discipline. Thus, a collaborative network may offer new faculty the opportunity to be mentored by colleagues in their own field.

Table 1. EREN Members' Survey Results

"My participation in EREN has..."	% of "Agree" plus "Strongly Agree"
Led to research in new areas	94%
Led to spin-off research projects	77%
Improved my research productivity	74%
Provided me with valuable training outside of my own subfield	87%
Helped me achieve tenure or promotion	51%
Enhanced my undergraduate research program	85%
Improved my professional credibility	72%
Improved my network of professional contacts	94%
Led to more students doing research in classes	68%
Led to more students doing independent research	62%
Created opportunities for publicity	64%

Notes: Based on 47 respondents (15% response rate). EREN survey options ranged from "Strongly Agree" to "Strongly Disagree."

The benefits of collaboration extend beyond new faculty to more-experienced faculty and include exposure to new research insights and technical skills. Indeed, 94 percent of survey respondents reported that their participation led to research in new areas, and 77 percent said that it led to spin-off projects. A collaborative network creates an exciting melting pot of ideas that helps to refresh and renew research skills and enthusiasm. The research protocols that have been devised for EREN projects may lie outside a researcher's individual experience, but the lead scientists offer advice, expertise, and sometimes even hands-on training, which allows collaborators to move beyond their disciplinary comfort zones and expand their repertoire of ecological techniques. For example, the TurtlePop project described above involves several aquatic wildlife ecologists but also a marine ecologist, two biogeochemists, two terrestrial-animal ecologists, and five terrestrial-plant ecologists.

Beyond the opportunities for mentoring new faculty and building research capacity, EREN also helps PUI faculty to expand the scale and scope of their research. In some scientific fields a single result is transformative, but ecology is so context-dependent that greater insight is almost always gained when a study can be replicated across environments. The large-scale, collaborative projects that EREN promotes allow us to collect landscape and regional-scale data that may lead to discovery of new patterns. These types of studies are only possible with a large cadre of researchers distributed across a wide geographic area.

One of the more tangible benefits of EREN is access to a diversity of curricula and protocols for experiential learning. Ninety-one percent of survey respondents use a collaborative EREN project in at least one course (1.8 courses on average). Teaching is the primary focus at most PUIs and help in devising useful experiential exercises is valuable for PUI faculty. EREN protocols are piloted by multiple institutions to garner feedback and suggestions for improvement before being widely implemented across the network.

Faculty members choose to join EREN because it offers a range of benefits for members. Currently, there is no membership fee and travel to annual meetings has been subsidized. If, as is true in EREN, faculty can choose their level of involvement, then collaborative research networks offer support with very little cost to most individual members. For networks to function, though, some members must be willing to take on administrative duties. Our sense is that most faculty members take on these tasks because of their sense of ownership and stake in the success of the network. Although other collaborative networks may differ in size and structure, we suspect that the creation of networks in almost any field would help PUI faculty find research collaborators, rekindle their enthusiasm for research, broaden their research programs, involve more undergraduates, and expand their toolkit of teaching activities.

Collaborative Network Benefits for Student Researchers

As its name implies, the fundamental premise of EREN is that research experience can be a highly effective educational approach (Bauer and Bennett 2003; Seymour et al. 2004; Russell et al. 2007). Learning develops within and flows from research experiences, leading to excitement about scientific discovery. Well-structured research engages students and stimulates curiosity and independence. The *Vision and Change* report on undergraduate education in biology (Brewer and Smith 2011) called for improving biology education by integrating undergraduate research into the curriculum, especially in the first or second year of college, for all students regardless of their major. This report cites a number of studies showing a link between student research and lasting learning. Student research improves the ability to understand how scientific studies are conducted and prepares students to evaluate scientific claims seen in their everyday lives. These experiences often lead to gains in confidence, motivation, and learning, as well as personal identification as a scientist and interest in scientific careers (Nagda et al. 1998; Seymour et al. 2004; Graham et al. 2013).

In EREN, undergraduates become participants in nationwide, long-term research projects by collecting, analyzing, and sharing data with other students. By participating in collaborative research, students become part of a community of scholars, which imbues them with a sense of belonging and responsibility (Light and Micari 2013). They also experience the challenges (e.g., communication and coordination) of collaborative research and learn to develop solutions (e.g., shared understanding, written policies, and detailed metadata) to questions that arise about methods, data ownership, and authorship that would not be encountered in traditional models of solitary research. Because participating faculty are trained more broadly, their students will be exposed to a wider range of techniques and subfields of ecology than they would be without the network.

Undergraduates from St. Olaf College, Ellen Squires and Hannah Marti, process leaf decomposition bags as part of a nationwide collaborative research project in ecology.

Assessment of student learning is underway within EREN at several different levels. The data-collection phase of a broad assessment effort involving 16 EREN institutions, focused on learning goals that extend across the diverse EREN projects, was completed in December 2015. Our hypothesis is that while EREN projects ask different ecological questions, all of them focus on collaborative, multi-site science and, therefore, participation in an EREN project has the potential to improve students' understanding of core themes and skills common to all projects. These skills include developing hypotheses for multi-site studies, thinking across scales, managing data from multiple sites, and describing techniques for multi-site collaboration. Preliminary analyses indicate significant improvements for some of these broad student-learning outcomes, particularly use of best practices in data management and describing scientific collaboration techniques (L.J. Anderson, unpublished data).

Individual EREN projects are also developing assessment

tools that are focused on the specific content and research skills associated with that project. Some individual curricular activities have been assessed and demonstrate learning improvements. For example, a pre-/post-test was used to evaluate improvements in student knowledge after two laboratory exercises on stream temperature. The 15-question, multiple-choice test was administered to 58 students at six institutions before and after they completed the two modules. Overall, student scores increased by 28 percent, which was a significant improvement (paired t-test, $p < 0.001$, Figure 1).

Faculty development is an important component of a collaborative research network. Here Dr. Karen Kuers (2nd from left) leads a training workshop on forest ecology technique for colleagues from other institutions.

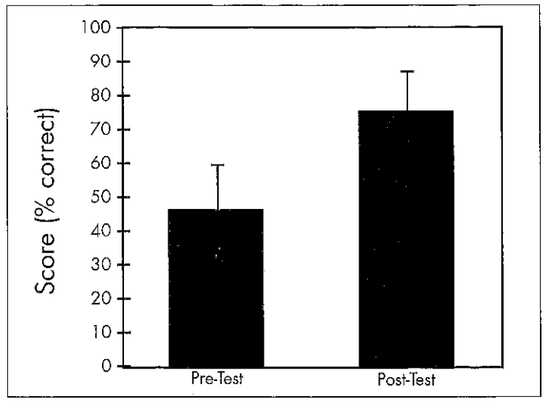
Benefits for Undergraduate Research Programs

Undergraduate research programs reap a substantial benefit from faculty members' participation in EREN. A large majority of survey respondents (87 percent) believed that they received valuable training from EREN, and 85 percent believed EREN enhanced their undergraduate research program (Table 1). Training in field and laboratory techniques outside of their area of expertise expanded the range and diversity of potential undergraduate research projects, which could result in more broadly trained undergraduates.

As described above, the research projects themselves have become educational resources that are incorporated into courses at all levels, as well as into independent research projects. Furthermore, because data collection happens nationwide instead of at one location, PUI students are now able to investigate large-scale ecological questions and gain experience working with "big data."

Collaborative research networks add excitement to the classroom and lab. In our experience, students' interest and motivation are piqued when they discover they will be part of a national-scale, multi-institutional research project. For 68 percent of survey respondents, participation in EREN resulted in more students doing research in class, and for 62 percent of respondents, more students doing independent studies. Moreover, faculty participants seemed to gain some prestige-by-association. A large and productive collaboration can generate media attention and publicity that could enhance the academic reputation of an institution and aid in recruitment of students to the research program. Sixty-four percent of survey respondents reported participation in EREN created opportunities for publicity, and 72 percent of faculty respondents reported that their professional credibility was enhanced (Table 1). EREN projects have already been the subject of numerous local news stories, community presentations, and a PBS video segment (http://mountainlake.org/programs/outdoors/colgate-university-team-visits-adirondacks-to-study-earthworms/).

Figure 1. Mean Pre-test and Post-test Scores from Assessment of an EREN Laboratory Activity on Stream Temperature (n=58)



Note: Error bars represent ±1 standard deviation. The post-test scores were significantly higher than the pre-test scores ($p < 0.001$, paired t-test).

Finally, collaborative networks can increase the efficiency of small institutions with tight budgets by leveraging resources (Lindquist et al. 2011). Faculty receive cross training in particular subfields of ecology from peer experts and pass on those teachings to colleagues and students at their home institutions, exposing them to a wider range of techniques and subfields of ecology than would be possible without this network. For example, an immunologist, a developmental biologist, and a limnologist at Elizabethtown College were trained to lead their students into the ponds when TurtlePop was incorporated into the general biology curriculum there.

Collaborative research networks are occasionally found in other disciplines. For example, the Keck Geology Consortium (http://www.keckgeology.org) and the Keck Northeast Astronomy Consortium (http://astro.swarthmore.edu/knac/) are long-standing, successful programs. Faculty design summer research projects, and then students from inside and outside the consortia apply to participate. Students develop and complete their own subproject and present their results at each consortium's annual research symposium. These two programs share many common elements with EREN, including a focus on providing research opportunities for undergraduates, inter-institutional collaboration among students and faculty, and sharing of resources and instrumentation. Faculty members have the freedom to determine their own level of participation, and each project is overseen by a project director.

EREN differs from the Keck consortia in that its focus has been more on faculty development and tying the research to classroom teaching. The key to success for all of these programs seems to be in constructing a framework within which faculty have 1) the flexibility to design their own projects, 2) access to a pool of interested undergraduates, and 3) incentives for participating (funding, opportunities to publish or present, leveraging of resources).

EREN serves as a case study demonstrating the dramatic, synergistic benefits of collaboration among ecology faculty at PUIs across the country. Faculty members benefit from professional development, expanding their research programs and gaining access to teaching resources. Connections among participants create a larger sense of belonging to a community of scholars who are in similar circumstances. Student learning is enhanced through greater motivation, exposure to more techniques and ecological concepts, and direct experience in a large collaborative research endeavor. We encourage other disciplines to explore the possibility of establishing their own collaborative research networks.

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