INQUIRY & INVESTIGATION

Using Inter-institutional Collaboration to Generate Publishable Findings through Course-Based Undergraduate Research Experiences

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Abstract

Course-based undergraduate research experiences (CUREs) are high-impact practices that allow students to conduct research during class time. Benefits of a CURE can be maximized when integrated into a faculty member's ongoing research. However, this can be particularly challenging for field biologists, especially when field sites are not situated near their university. Indeed, few existing CUREs are field based. One solution is to partner with a collaborator near the field site. We describe a semester-long CURE in an animal behavior class that involved collaboration among three institutions: researchers from two "distant" institutions have ongoing research at the "local" institution where the CURE took place. This model uses remote conferencing and strategic collaboration to meet all stakeholders' needs. Undergraduate students engaged as active participants in collaborative inquiry-based work, learned in a cooperative context, and even participated in the publication process. The local principal investigator and their institution generated a high-impact course that integrated research and teaching. Likewise, the distant principal investigators were able to collect more extensive and longer-term field-based data than otherwise possible, and they gained valuable input from the local researchers that contributed to future projects. Remote collaborations open the door to international collaboration with smaller institutions, promoting greater inclusion in science.

Key Words: *CURE; field course; mentorship*; Teleogryllus oceanicus.

Introduction

Course-based undergraduate research experiences (CUREs) have become an increasingly common way to provide research experience to a large number of students (Auchincloss et al., 2014). While traditional undergraduate research experiences (i.e., mentored research in a faculty member's lab) are incredibly valuable, universities rarely have the capacity to provide such experiences for all students. By building engaging research experiences into the structure of a course, CUREs have the potential to alleviate this problem by providing valuable experience for students while reducing the out-of-class commitment for both students and their mentors, compared to traditional one-on-one research mentorship (Lei & Chuang, 2009). CUREs can benefit student participants by increasing engagement in the course (Shortlidge et al., 2017), involving students in research early in their undergraduate career to lay a foundation for more advanced research experiences as upper-division students, and increasing their likelihood of graduation with a STEM (science, technology, engineering, and math) degree (Rodenbusch et al., 2016; Shortlidge et al., 2016). Benefits of CUREs to faculty include the training and recruitment of students to their own lab for traditional research experiences, development of preliminary data that can be used in grant applications, and the potential to develop meaningful broader impacts like research projects that are relevant to their community (Shortlidge et al., 2016). While the benefits of CUREs are readily apparent, most reported examples have been conducted in laboratory settings (Thompson et al., 2016; Sorensen et al., 2018; see examples in Wei & Woodin, 2011), leaving untapped potential in more field-intensive disciplines within the biological sciences.

A challenge for implementing field-based CUREs is that field sites of university researchers are often not located near their home institutions. This could contribute to the trend that most CUREs are stand-alone opportunities, designed to fit within a single semester, and, as a result, are not necessarily linked to a mentor's research project (Brownell & Kloser, 2015; Russell et al., 2015). By designing CUREs that can be executed in the field, field biologists could more easily implement experiences that build on ongoing research, which has numerous benefits. For example, the incorporation of CUREs into ongoing research, rather than designing a stand-alone CURE, could help institutions overcome some of the logistical or social barriers (e.g., time, resources, and institutional support to develop new course materials) that might dissuade a mentor from designing and implementing a CURE (Spell et al., 2014; Bakshi et al., 2016). Furthermore, by incorporating a CURE into ongoing research, mentors can spend less time developing research experiences (Spell et al., 2014), provide more genuine experiences that are directly relevant to their expertise (Bakshi et al., 2016; Shortlidge et al., 2016), and gain more of the tangible positive outcomes associated with developing their own

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CUREs rather than adapting preexisting ones (Shortlidge et al., 2017). Finally, a well-designed and well-executed CURE can be a valuable source for data collection, including long-term data, thus increasing the research productivity of both students and mentors (Dubansky et al., 2013; Porter, 2015). Thus, it is important that approaches be developed that facilitate the design and implementation of field-based CUREs.

We challenged ourselves to develop a model for a field-based CURE that could be used to build inter-institutional collaborations and facilitate the collection of field data in remote field sites. Our proposed model links students at a primarily undergraduate institution (PUI) with researchers conducting long-term research near the campus of the PUI through regular online connection and limited in-person training. Together with the local (i.e., from the PUI near the field site) and distant principal investigators (hereafter "local PI" and "distant PIs," respectively), students designed a semester-long field project to address hypotheses of mutual interest. Given the international composition of the student body at the host PUI, this particular example holds great potential for building international collaborations as students return to their home countries. A major potential strength of our proposed model for mentorship and collaboration is that it facilitates the alignment of teaching/research efforts with faculty and student goals outlined in the AAAS *Vision and Change* document (AAAS, 2011). For faculty, our model supports the "development of a true community of scholars dedicated to advancing the life sciences and the science of teaching" (AAAS, 2011) by bringing together faculty from distant universities with a common goal of providing students bona fide research experiences. Our model aligns with *Vision and Change* goals such as (1) engaging students as active participants in the scientific process; (2) ensuring that undergraduate biology courses are active, outcome oriented, inquiry driven, and relevant; and (3) facilitating student learning within a cooperative context (AAAS, 2011). Below, we describe the structure of this field-based collaborative CURE and discuss the potential benefits of implementing such a CURE for both faculty and students.

○ Structure of the Inter-institutional Field-Based CURE

Below, we outline the participant groups, their specific roles in this case study, and the methods of communication that facilitated the collaboration. The inter-institutional CURE involved the local PI teaching an animal behavior class and accompanying lab, in which all participants developed a new semester-long project related to the research program of the distant PIs (see below for course description).

Participant Groups

Productive collaboration between multiple institutions, investigators, and students requires organization and an understanding of the specific roles of different individuals within that collaboration. Within our model, there were several levels of mentorship that organically developed beyond those typical between a professor and students, facilitating training and professional development for individuals at multiple career stages (i.e., faculty, teaching assistants, and undergraduate students; Figure 1). Peer mentorship became a key component of the program and included interactions among the three PIs (one local and two distant), interactions among an experienced student teaching assistant (TA) and students in the course, and interaction among students in the class as they worked in small groups toward a common goal (Figure 1).

In this particular model, distant PIs who regularly conduct field research far from their own institutions collaborated with a local PI whose institution is near the field research site of the distant PIs. To assist in the planning and implementation of the animal behavior lab (see course description), the distant PIs trained the local PI on the study system and ongoing field studies while on site conducting research. The local and distant PIs then provided study-system-specific training to an undergraduate TA who had taken the animal behavior class previously. Data collection was then conducted by the class participants and overseen by the local PI and student TA with ongoing input from the distant PIs. After the course was completed, particularly exemplary and interested students were selected to participate in a writing group that is collaborating to write a publication based on the research conducted throughout the semester. During this stage, both the student TA and writing group received additional mentorship from the local and distant PIs on the study system, the broader literature, and the process of writing a paper for publication. Distant PIs then participated in all aspects of the process of manuscript preparation through online video conferencing and joint writing, providing feedback each step of the way.

The collaboration and mentorship in this proof-of-concept CURE ultimately benefited all parties in a mutualistic way (Figure 2). For instance, because the remote location of the field site (in relation to the distant PIs' institutions) causes field data collection to be costly and infrequent, collaboration with the local PI and CURE facilitated the collection of more and longer-term data than the distant PIs might otherwise have access to; simultaneously, students grew their academic networks and participated in inquiry-based and extensive place-based data collection.

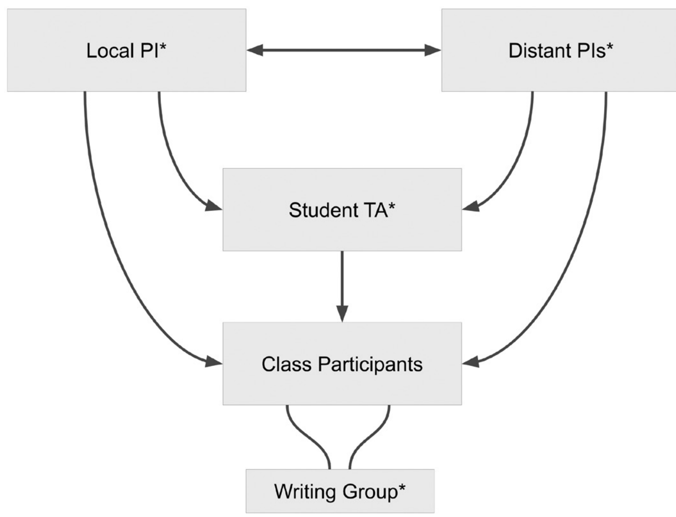

Figure 1. Schematic of participant groups involved in the inter-institutional CURE: Local and Distant Principal Investigators (PIs), Student Teaching Assistant (TA), Class Participants, and Writing Group. Arrows represent mentoring relationships. Asterisk denotes participation in follow-up publication.

		Recipients			
		Local PI	Distant PIs	TA	Undergraduate Participants
Donors	Local PI	High impact course; teaching- research integration; publications	Access to site and students; learn new mentorship style	Learn how to lead and manage students and a research experiment; recommendation letters	Hands-on research experience; mentorship; more engaging and meaningful lab experience
	Distant PIs	Learn new research system; learn new mentorship style	Preliminary data for grant applications; publications; potential recruitment of new students	Connections with PIs "abroad"; learn new research system and field methods	Introduction to study system; place-based research; exposure to a diversity of scientists
	TA	Assistance running course; bridge to undergraduates, share feedback	Facilitates generation of longer-term data; opportunity to mentor new student	Publications; expanded professional circles; professional development	Peer mentorship; knowledge of study system and local biology; model of scientific process
	Undergraduate Participants	Positive evaluations; publishable data	Longer-term publishable data; new observations	Leadership experience; teaching experience	Worked collaboratively in diverse teams; transferable skills; insight into research careers/grad school

Figure 2. Inter-institutional CURE participants benefited in mutualistic ways. The participant at the top of each column (recipient) benefited from its interaction with the participants in each row (donor). The gray boxes show positive outcomes (for the participant at the top of the column) that do not stem from any one participant. TA = Teaching Assistant; PI = Principal Investigator.

Course Description: An Applied Example of a Field-Based CURE

As already mentioned, this collaborative model involved an upper-level animal behavior course with a lab. The lab consisted of two weekly meetings (each lasting two to three hours and involving only half of the class participants), allowing for increased replication of the experiment over the course of the ten-week sampling period. While the lab project was conducted separately from the lecture sessions, the content of the research lab was directly related to lecture units such as signaling and cues, mating behaviors, sexual selection, and natural selection. The CURE project focused on the evolution of sexual signaling in field crickets found in Hawaii. The distant PIs involved in the ongoing project were based in two different universities in the contiguous United States, but they assisted in the development and implementation of the CURE (taught at the campus of the PUI) as described above.

While many topics were covered over the course of the project, the experience as a whole was designed to target specific skills-based learning outcomes in alignment with the *Vision and Change* document (AAAS, 2011). We focused on the following outcomes: learn a new research study system by reading papers and meeting with experts; design methods with researchers who work in this system; conduct a long-term experiment; evaluate the experience of conducting publishable research; and discuss future research ideas and hypotheses.

Study System, Experimental Design & Field Methods

Pacific field crickets, *Teleogryllus oceanicus*, are a valuable system for studying rapid evolution and are useful teaching tools because they are easy to handle and exhibit easily observable behaviors (e.g., Tinghitella, 2015a, b). At night, male crickets produce a loud calling song with their wings to attract female crickets for mating, but on the Hawaiian Islands these loud songs also attract an introduced parasitoid fly, *Ormia ochracea*. Gravid female flies locate cricket hosts using song and then spray larvae on the cricket from above, which burrow inside to devour the cricket alive (Cade, 1975). Putatively in response to this selective pressure from flies, at least two new male cricket morphs have evolved: an obligately silent morph (Zuk et al., 2006) and, more recently, a purring morph (Tinghitella et al., 2018). Purring crickets produce a song that is quieter than the ancestral song, and there is tremendous variation in the songs of purring males. In the laboratory, some female crickets can use the purring songs to locate mates, but more females respond to the ancestral song than to the purring song (Tinghitella et al., 2018). Similarly, in the lab, flies are able to locate speakers broadcasting purring songs over short distances, but in preliminary trials we caught flies only when we broadcast ancestral song from fly traps in the field (Tinghitella et al., 2021). One of the big remaining questions is how female crickets and flies respond to different purrs in the wild, and answering it would help us understand how sexual selection (female crickets) and natural selection (female flies) are acting on the new purring sexual signal. In order to answer this question, the distant PIs needed help to record the number of flies and crickets attracted to a variety of purring songs in a natural population with adequate replication over time and space. This experiment was logistically impossible for the distant PIs who visit the field (six sites across the Hawaiian Islands) for about three weeks twice per year.

In order to quantify the selection that female crickets and flies exert on purring songs, undergraduates in the CURE at the local institution conducted a 10-week field phonotaxis experiment (adapted from the methods of Zuk et al., 2006) in which we played the ancestral typical song plus eight different variants of purring song that captured the natural variation in the new signal, and we recorded which animals were phonotactic (attracted) to the songs. We hypothesized that flies and crickets would both prefer ancestral song but would have different, nuanced preferences for the purring variants. Before the semester began, the distant PIs, local PI, TA, and select students worked together during virtual and face-to-face meetings to design an experiment to test this hypothesis (Figure 3A). The TA helped make decisions about questions of experimental design such as randomization of treatments, use of appropriate controls, and how to optimize student participation. This exposed the student TA to important background processes of scientific research as well as more general experimental design principles. Once the course began, the TA acted as a bridge between the PIs and the students to lead the semester-long program, which was broken up into 15 weeks (Table 1). Table 1 identifies the manner in which participants contributed, as well as the methods we used to promote regular and ongoing communication among the local and distant PIs, TA, and undergraduate students.

After introducing class participants to the study system and experimental design, the TA divided the students into eight teams of three in order to maximize the efficiency of data collection and provide the students opportunities to gain experience working in small teams. Four teams participated in two separate weekly field sessions. Student teams were each responsible for three phonotaxis trials. For each trial, students collected and identified all crickets in a circle with a 2 m radius (juvenile, female, ancestral male, purring male), removed them from the circle, then played a randomly assigned male cricket song from a speaker, and finally collected and identified all crickets in the circle after 20 minutes. Students rotated through several roles, including data keeper and animal handler, allowing each student to gain experience with data management, animal handling, animal identification, and execution of experimental protocols. Furthermore, the TA guided the students in developing and practicing troubleshooting and problem-solving skills, including managing technological malfunctions related to phonotaxis equipment (speakers, mp3 players, flashlights) and responding to unpredictable field conditions (e.g., fluctuations in weather and habitat conditions). Finally, during the last weeks of the semester, students reflected on the experience and proposed ideas for future research. A select group of motivated students continued in a writing group where they analyzed data, created figures

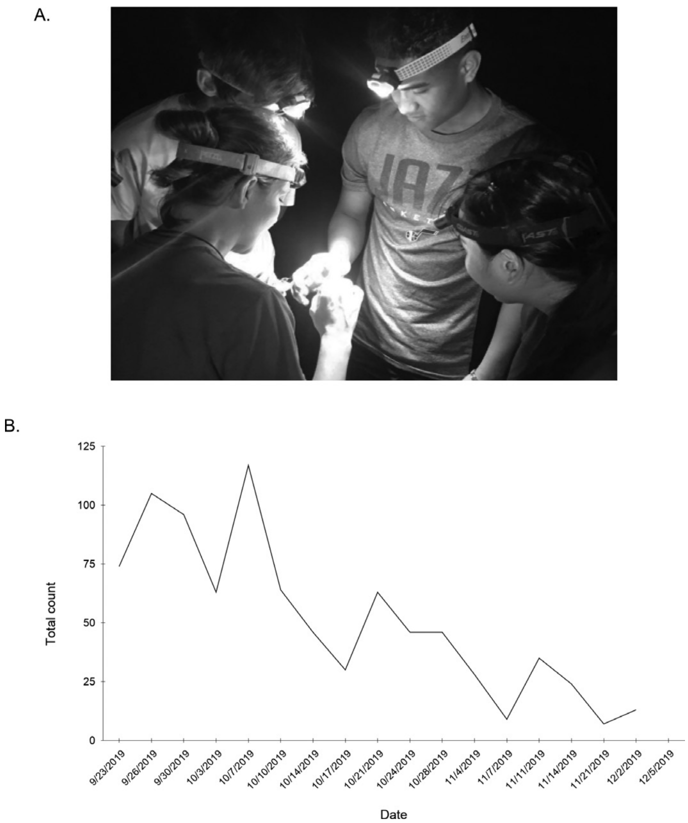

Figure 3. (**A**) Students training in cricket field methods. (**B**) An example figure created by members of the writing group in the CURE showing one of the results (total number of crickets counted per sampling night) from the field experiment.

Table 1. Week by week programming of the collaborative CURE.

Week	Activity
Pre-semester	In-person meetings and methods training in Hawaii during distant PIs' field season; video conferences between distant and local PIs, supplies exchange, and other pre-course project planning
1	Introduction to lab: (1) Overview of study system, (2) Intro to research questions and objectives, (3) Description of field techniques, (4) Group assignments
2	Field techniques training (evening meeting): (1) Phonotaxis protocol, (2) Identifying sex and wing type, (3) Deploying fly traps, (4) Data recording
3	Video conference between all participants (students, TA, local and distant PIs)
3–12	Evening fieldwork with student teams, supervised by TA and local PI
13	Debrief and discussion of data analysis and interpretation

Table 1. (*Continued*)

Week	Activity
14	Face-to-face meeting between select students and distant PIs in Hawaii
15 and on	Weekly video conferences with a select writing group (during these weekly conferences, the PIs, TA, and selected students work on analyzing data and preparing a manuscript for publication)

(for an example, see Figure 3B), and worked collaboratively on a manuscript for publication.

○ Student Impressions of the CURE

Our inter-institutional CURE model was designed to benefit all participants (Figure 2) and to align with student learning goals outlined in the *Vision and Change* document (AAAS, 2011). In particular, we engaged students as active participants in all components of the scientific process, conducted an inquiry- and place-based experiment, and facilitated student learning in a cooperative context. Student reflections in anonymous end-of-course evaluations (Table 2) echoed these goals, citing discussion with primary researchers, hands-on research experience, and application as strengths of the course. In a lab writing assignment in which students were asked to reflect on what they had observed and learned in the course (Table 3), they focused on developing a real understanding of what goes into behavioral data collection, troubleshooting in field studies, and real-life and career application. Overall, student response was overwhelmingly positive.

Table 2. Student responses from anonymous course evaluations, in which students were asked to comment on what they perceived as strengths of the course.

"Clear explanations and examples for class"
"Consistency makes it easier to know what to expect each lab. I learn well that way"
"Doing the hands on cricket research helped me effectively apply what I learned throughout the semester to real research. I liked how it was presented in the beginning, especially the discussion with the researchers heading the project"
"Dr. Ingley creates a great learning environment where we learn from both lecture and class discussion. There were plenty of examples that made concepts more understandable"
"easy and enjoyable"
"hands on experience"
"Hands on"
"Love the fact that we don't have to do lab write ups every week. It's interesting to observe crickets"
"Out of class preparation helps to understand the material in class a lot. Teacher led discussions were super helpful in learning and making connections"

Table 2. (*Continued*)

"Student involvement and value. Actually learning and applications"
"Supa-dupa practical lab experience and the write up is great practice for writing papers later on"
"The course allowed for hands-on field work experience that was repetitive, which allowed for students to understand the nature of many field work studies"
"This lab gave good practice on real life methods and research practice that would be used in a future career in this area. It gave us the opportunity to have hands on experience in real time evolution and seeing the benefits and consequences of that"

Table 3. Select excerpts from a lab writing assignment in which students were asked to reflect on what they had observed and learned about the study system, about topics discussed throughout the course, and about the scientific process generally.

"The things I've learned so far is the amount of time and data that takes to understand the behaviors of a species of animal. This is due to factors that change in the real world. In a controlled laboratory environment, things usually go in a set pattern according to plan. Such as growing bacteria or microbes. Even sometimes expectation of the experiment changes, the results and answers can be found in a relatively short period of time. The crickets on the other hand requires a lot of trails and time to gather the data, as the factors that we are able to control are limited, these include the environment whether the grass is long or short, the weather whether if it's hot, cold, dry or wet, and the crickets themselves if they want to appear or not that day."
"This laboratory experience has been an interesting one. It has definitely been by far one of the best scientific experiences I have had. It has been very fulfilling to actually be able to go out and do field work of sorts."
"I found this lab very interesting and entertaining, and I'm glad that the principles we learned from the experiment coincided with the concepts we were learning in class. I feel as though I am more prepared to conduct my own experiments in the future about the topics we learned in class because of the hands-on experience I was able to gain. My understanding of animal behavior and its real world application has grown tremendously throughout this semester, as has my understanding of its importance in the real world."
"If there is one thing I learned from this semester's Animal Behavior Lab it is that the study of animals and their behavior (mating, calls, selection, etc.) requires dedication from the biologist. It isn't an easy task to do the same test hundreds of times, but it is necessary in order to understand trends and behavior. I'm grateful for the experience I have had!"
"In conclusion, the cricket lab this semester was fun, practical, and had a lot of real life applications."

○ Summary & Recommendations for Implementation

The proof-of-concept CURE described here included long-distance collaborations and mentorship at many levels. In addition to collecting valuable data in an exciting study system, all participants benefited from all other participants in a mutualistic way (Figure 2). This CURE also had some other, unanticipated positive outcomes. The first was revealed by the COVID-19 pandemic. Because writing-group meetings were always intended to be online so that the distant PIs could participate, the infrastructure of our ongoing virtual meetings was largely unaffected by closures (for communication infrastructure, see Table 1). Preplanned, regular virtual communication thus created project resilience. Therefore, one recommendation is to invest sufficient energy up front in designing a communication plan and clear expectations for all participants.

An additional benefit that emerged for the distant PIs, in particular, was the opportunity to collaborate with diverse students. The distant PIs are located at homogeneous private institutions, while the local institution has a very diverse student body and one of the highest proportions of international students of any school in the United States, with a particularly high representation of students from Oceania. Diverse research groups are beneficial in that diverse groups are more creative, have higher performance, and produce higher-impact research than homogeneous groups (McLeod et al., 1996; Hong & Page, 2004; Freeman & Huang, 2015). Through this collaborative project, we built a small international community of students and faculty that became a valuable social network during the global COVID-19 pandemic and beyond.

What will we change the next time we implement this CURE? In our initial implementation of this model, we spent the most time on data collection as well as development of the experimental protocol. However, we did not build time into the semester for students to dig deep into initial experimental design or work with the data and present findings. The writing group, which consisted of a subset of students, did work on data analysis and a scientific paper for publication the following semester, but the larger class would likely have benefited from both increased involvement in early stages of experimental design and dissemination of the research, as dissemination can increase self-efficacy and interest in careers in STEM (Broder et al., 2019). One solution would be a three-semester course, in which successive semesters focus on experimental design, data collection, and data analysis and dissemination, respectively. Another model might be a cohorted learning community where the students participating in the CURE animal behavior course simultaneously take, for example, a biological statistics course and a science communication course where they work with data they collect in the CURE. Finally, depending on the length of the CURE project and the size of the course, more time could potentially be built into the semester to allow students to participate in data analysis and presentation of findings. Given the small size of the class used for this CURE, it was necessary to spend much of the semester on data collection in order to have sufficient sample sizes.

The model we present here lends itself to a diversity of class sizes. For this first implementation, we had a relatively small class (21 students), which allowed us to conduct two parallel, related experiments and still collect enough data to answer our research questions. With a larger class size, there are several possibilities. For example, multiple projects could proceed in parallel, with students rotating among different projects so that they get experience with diverse data collection approaches and several related research questions. Another possible adaptation would be dividing the students so that smaller groups are responsible for entire research projects rather than having all students work on all projects. This would potentially be repetitive, but participants of this CURE noted a perceived benefit of experiencing the repetitive nature of data collection (Tables 2 and 3) that is a hallmark of science. Additionally, working on one experiment for the entire semester could give students a sense of ownership and autonomy that might increase scientific self-efficacy, as was reflected in student comments from this CURE (Tables 2 and 3).

Although this proof-of-concept CURE was small in scale, it has far-reaching implications. We built a collaboration that created a social network, which has laid the groundwork for international collaboration as student participants graduate and return to their home countries. It exposed undergraduate students to cutting-edge science and remote scientists to which they otherwise would not have been exposed, and the distant PIs collected valuable data in a more sustainable way, since overseas travel is environmentally and economically expensive. While we still have much to learn, we encourage other laboratories to use this CURE as a model to build mutually beneficial mentorship networks that integrate research and teaching.

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