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Lessons Learned from Educational Research of a National Science Foundation Research Experiences for Undergraduates

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Abstract

Participation in an archaeological field school is the entry point to a professional career in the discipline. Despite the importance of field schools, few scholars have investigated achieved student-learning outcomes or lasting impacts on students from participation in archaeological field research. We report on the educational design, learning objectives, and results of three years of formative and summative assessments for an interdisciplinary, archaeology and ecology research program for undergraduate students. Our learning objectives include promoting scientific literacy and communication, critical thinking and STEM skills, and capacities in archaeological and ecological interdisciplinarity. Using developed rubrics that account for both critical thinking and STEM understanding, self-administered competency surveys, and program-developed items, we found significant gains in nearly all learning objectives. Students demonstrated growth in program specific content, perceived abilities in their scientific and discipline specific skills, critical thinking skills, and scientific communication skills. These educational outcomes and assessment tools have implications for how we design and evaluate field learning in archaeology and may be applied to field school instruction.

Over the last century, archaeological undergraduate education has emphasized the need for students to acquire skills in field methodologies by requiring students to complete a field school: an immersive, participatory course where students learn practical field methods (Baxter 2009; Gifford and Morris 1985; Mytum 2012a). The emphasis on field school preparation for anthropology baccalaureate graduates to acquire a job in the field continues to this day (Aitchison 2004; Boytner 2012; Cobb and Croucher 2012; Perry 2004; Walker and Saitta 2002). Though field schools have been a significant teaching tool to train future archaeologists, scholars have given little attention to the various models for field school instruction or to the documentation of the educational effectiveness of field schools (but see, Baxter 2009; Brookes 2008; Everill 2015; Lightfoot 2009; Mytum 2012a; Perry 2004). With the field school serving as the primary tool to teach students how to do archaeology and be an archaeologist (Cobb and Croucher 2012), it is important that field school directors evaluate the teaching effectiveness of field schools and develop and test new models of field school pedagogy.

In this paper, we review the process of developing an educational evaluation strategy for a field-based, interdisciplinary summer research program, a National Science Foundation Research Experiences for Undergraduates (NSF REU), and the educational results from this program. Further we provide suggestions regarding how field school directors can evaluate the educational outcomes of their field schools.

We do not consider the NSF REU we designed and implemented to be the same as a traditional archaeological field school; however, there are many similarities. We structured the program and several educational activities on a field school model. Our REU included immersive, rigorous, and demanding field-based learning activities in both archaeology and ecology. Students lived in close proximity to the field sites away from other undergraduate students, forming a cohort-like learning and living environment typical of many field schools (Cobb and Croucher, 2012; Mytum 2012b). Further, several student participants reported that this experience confirmed that they did have the desire and passion to pursue a career in research—a sentiment often expressed among archaeological undergraduate students after completing their first field school experience (Boytner 2012; Perry 2004). We also compare our model of field instruction with that of a traditional field school. We discuss the advantages and disadvantages of our model and suggest elements of our field-learning model that could be integrated into the traditional field school model.

National Science Foundation Research Experiences for Undergraduates

The National Science Foundation Research Experiences for Undergraduates supports active research participation by undergraduate students in established research programs among all disciplines for which the NSF makes awards (National Science Foundation 2019). Though specific program designs vary, typically REU sites support eight to 12 students each year during a six to 12-week summer research program. Award duration is limited to three years, and award recipients may reapply for funds, extending the duration of the program beyond three years. Through this program, undergraduate students recruited from throughout the United States engage in active research programs and are guided through the entirety of the research process by faculty mentors, graduate students, and other scholars. Importantly, students should have an active role in formulating and conducting their original research. They should be instrumental in all parts of that research, not simply a member of the field crew or an assistant who performs one singular task of a larger research question. Students, with guidance from their faculty mentor, should be the drivers of their research.

The NSF suggests that particular student groups such as freshmen, sophomores, women, veterans, students from underrepresented ethnic and racial groups, and non-traditional college students should receive selection preferences (National Science Foundation 2019). This funding line does require that students receive a stipend for their work during the program, unlike many field schools, and students generally are provided with free housing accommodations while conducting their research.

In the summer of 2014, we (Colaninno and Chick) began developing a research program that centered on the concept of deep-time, human-environmental interactions at the confluence of the Mississippi and Illinois rivers (Colaninno et al. 2017). Our research compared riverine fish community structures in the distant past (i.e., pre-contact archaeological time periods) with current riverine fish communities from the same locations represented in long-term ecological monitoring programs.

Given our research focus and the alignment with archaeology and ecology concepts, we envisioned a program where interdisciplinary student teams (1 archaeology student and 1 ecological student) could develop unique research hypotheses related to long term changes in human actions, modifications, and management of these rivers and the surrounding landscape that could be tested through statistical comparisons of ichthyofaunal collections and modern fish community samples.

The research program we built integrated the archaeological and ecological perspectives on human-environmental interactions, providing an ideal framework for undergraduate students to learn about the benefits, limitations, and nuances of interdisciplinary research. We thought there was a strong potential for student learning through participation in this type of research (Kober 2015; Linn et al. 2016) and we designed a program where anthropology and ecology undergraduate majors could actively engage in this research. Importantly, we aimed to recruit and primarily select students who self-identified as first generation college students: students whose parents do not hold a college degree. Research demonstrates that there is a persistent degree attainment gap between those students whose parents have at least a bachelor's degree, and those students whose parents do not (Engle and Tinto 2008). As such, a field-based research program designed specifically for first generation college students with strong mentorship could help these students persist in college.

Through this program, students worked in teams to learn archaeological and ecological field methods. Archaeological training included two weeks of excavations and associated processes for documenting archaeological excavations such as mapping, shoveling, troweling, profiling, flotation sampling, and soil description. Ecological training included four weeks of field identification of live fish, measuring and recording environmental data including water temperature, conductivity and dissolved oxygen content, and basic habitat characterization such as the presence or absence of aquatic vegetation, woody debris, and/or rocky substrate. Students also learned ecological laboratory procedures for identifying preserved fish and zooarchaeological lab procedures identifying the skeletal remains of animals recovered from archaeological sites with a particular emphasis on fish skeletal remains (Wheeler and Jones 1989).

Modern, long-term fish data and fish sampling activities were associated with two long-term research programs: 1) the Long Term Resource Monitoring (LTRM) element of the US Army Corps of Engineers' Upper Mississippi River Restoration and 2) the Long-term Survey and Assessment of Large-River Fishes in Illinois (LTEF). These research programs conduct annual sampling of fishes using electrofishing and several types of nets in a number of different habitats in the Mississippi and Illinois rivers according to highly standardized protocols designed to sample the entire fish communities in these rivers (Ratcliff et al. 2014). Students also learned interdisciplinary methods that span both ecology and archaeology such as stable isotopic applications (Colaninno et al. 2019) and laboratory techniques to assess fish age and growth.

Students conducted their own research within the framework of understanding long-term changes to fish communities and riverine habitats as related to potential human actions. For our students, the field and laboratory training was not solely centered on field research, learning zooarchaeological analysis, or fisheries research; rather, we tasked them to formulate a hypothesis related to deep-time human-environmental interactions in the Upper Mississippi River System (UMRS), using a combination of existing data and data they collected to test their hypothesis, write their results, and present their research to scholars, peers, and the public.

Our program also included features to support undergraduates, particularly first generation college students, in their pursuit of a degree, as well as to introduce students to scientific investigations outside the specifics of our established research program. Each week, students would engage in student development sessions to help build their capacity and confidence as an undergraduate student and help prepare them for graduate school and/or employment (Blackwell and Pinder 2014; Graham et al. 2013; Harrell and Forney 2003). Throughout the program, we also invited colleagues to present their research to the students, giving them the opportunity to learn more about the various types of research questions scholars in each field investigate. We also facilitated critical reflection discussions each week so that students and program directors and staff could help students clarify and synthesize what they learned from week to week (Hatcher and Bringle 1997; Molee et al. 2011). This allowed students the opportunity to articulate the skills they learned and how those learned skills related to specific areas of research, as well as broad scientific inquiry (Grossman 2009). A high-level overview of the program schedule, including the main learning activities students engaged in are detailed in Figure 1.

The final product students produced was an analysis of two large databases, one ecological and one archaeological, to test a hypothesis related to anthropogenic changes in the UMRS over the past 2,000 years. Examples of student topics include questions related to changes in fish communities associated with: advances in human fishing technologies, human-induced alterations in the connectivity of rivers to their floodplains, human-induced changes in the distribution of submerged aquatic vegetation, and the introduction of invasive species such as the silver (*Hypophthalmichthys molitrix*) and bighead carp (*H. nobilis*).

On the last day of the program, each interdisciplinary team presented their research in the form of a scientific poster (Figure 2). This final symposium was open to

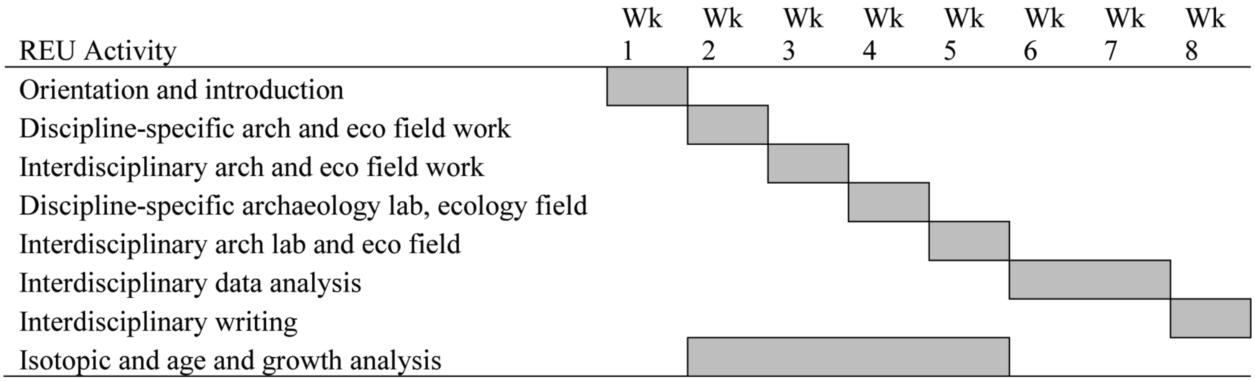


Figure 1. High level overview of REU program activities. The first week of the program included orientation, safety training, and an overview of the local and regional archaeological and ecological content. The second and third weeks students learned discipline specific field methods. For archaeology, this included excavations by shovel and trowel, feature excavations, unit mapping, feature mapping, profiling, soil descriptions, flotation sampling, artifact washing, artifact sorting, and collection management. During the fourth and fifth weeks, students learned zooarchaeological laboratory procedures including specimen taxonomic identification, element identification, element symmetry, indicators of age and sex, specimen weight, indication of modifications, MNI estimates, and selected primary and secondary data summaries. Students learned ecology field methods throughout the second through fifth weeks. Students worked as interdisciplinary teams in weeks three and five of the program, learning the methods from outside their undergraduate field of study.

the university community and public, providing students with the opportunity to present their research and findings in a scholarly setting.

Central to the success of our proposal and the program once funded, was the inclusion of detailed learning objectives for our prospective students and how we would measure their learning throughout the program (formative assessment), as well as at its conclusion (summative assessment). We designed the program and associated student-learning activities, based on five overarching learning objectives for this research experience.

Figure 2. An interdisciplinary team presenting their research at the final research symposium to scholars and the general public. Image courtesy of Howard Ash.

1. Improve students' critical-thinking skills. After engaging in this research program,

students would have a more critical understanding of the process for the scholarly pursuit of knowledge and how to pursue scholarly knowledge for themselves.

2. Improve students' scientific skills. After finishing the program, students would feel more competent in their archaeological and ecological field abilities as well as their abilities to conduct laboratory research.
3. Improve students' scientific literacy: Through the program, students would gain the ability to identify scientific hypotheses, experimental and observation research designs, and how researchers interpret data. Further, students would be able to understand how scholars design research to address a question?
4. Improve students' disciplinary and interdisciplinary understanding. Students would have gains in discipline specific content knowledge, as well as content that spans and bridges both fields.
5. Improve students' ability to communicate scientific concepts, research, and data: By the end of the program, students would have the ability to situate their research within a greater body of literature and effectively articulate and disseminate their research within that body of literature to others.

Though we developed clear learning objectives, we also needed to develop the means to assess whether students were achieving these learning objectives throughout the program and at its conclusion. To do this, we partnered with an educational evaluator (Feldmann) to develop formative and summative assessment tools for these five learning objectives.

Developing Educational Assessment Tools

Formative Assessment

One of our major concerns for program implementation centered on ensuring that students received the appropriate instruction and training to complete the research tasks assigned to them at any given point and that these tasks ultimately built the foundation for them to produce their final research poster. Further, we wanted to have the means to know if students were experiencing any issues with the program of which program staff may not be aware. Given the need to track student progress from week-to-week, we developed a formative assessment. This assessment was administered to students twice during the first week of the program and then weekly throughout the remaining seven weeks. These weekly surveys included items that asked students about their satisfaction with weekly activities, their confidence in their program specific skills, their overall satisfaction with their experience, and open-ended questions related to aspects of the program that were and were not going well for them (Figure 3). All items were on a 5-point Likert scale and were administered via email using online

What experience are you in? (Choices: Archaeology or Ecology)

Indicate your level of confidence from "Not at all confident" to "Extremely confident" using a 5-point Likert Scale.

a. How confident are you with your abilities to be productive with this summer research experiences?
b. How confident are you with your ecology skills?
c. How confident are you with your archaeology skills?

Indicate your level of agreement from "Strongly disagree" to "Strongly agree" using a 5-point Likert Scale.

a. I found the archaeology evening lecture this week informative and beneficial.
b. I found the ecology evening lecture this week informative and beneficial.
c. I found the student development session for this week informative and beneficial to my understanding of how to be successful in college.

Indicate your overall satisfaction with the REU program from "Not at all satisfied" to "Extremely satisfied" using a 5-point Likert Scale.

a. How satisfied are you with the summer research experience?

Open-ended Questions

a. What has gone well this week?
b. What would you change about this week?
c. What would you like to share with the program staff?

Figure 3. Weekly formative assessment survey administered to student participants twice during the first week and once each week for all following weeks.

survey software. Program staff received student responses each week, but responses remained anonymous to protect the students' identities and encourage honest responses.

Summative Assessment

Overall student learning objectives related to improvements in critical-thinking skills, scientific skills and literacy, disciplinary and interdisciplinary content understanding, and scientific communication. We developed a set of instruments to measure change in these learning objectives. All instruments were administered at the start (pre-assessment) of the program to assess pre-program levels and again at the end of the program (post-assessment) to assess gains. We detail these summative assessment instruments in this section.

To evaluate improvements in critical thinking, project staff used the Critical Thinking across the Curriculum rubric (Hooker 2005) assessing five components of critically thinking for each student at the start of the program and after participation. These five components include: 1) analyzing information, data, ideas, or concepts; 2) applying formulae, procedures, principles, or themes, 3) presenting multiple solutions, positions, or perspectives; 4) drawing well-supported conclusions; and 5) synthesizing ideas into a coherent whole. Program staff assessed each student's abilities in these five areas on a 4-point scale from "Beginning," "Developing," "Competent," to "Accomplished." Project staff considered these aspects of students' ability based on observations during scholarly discussions and field and laboratory practices. After working with these students for eight weeks, program staff reconsidered each students' ability in these five components.

Table 1. Example of STEM Skill Items.

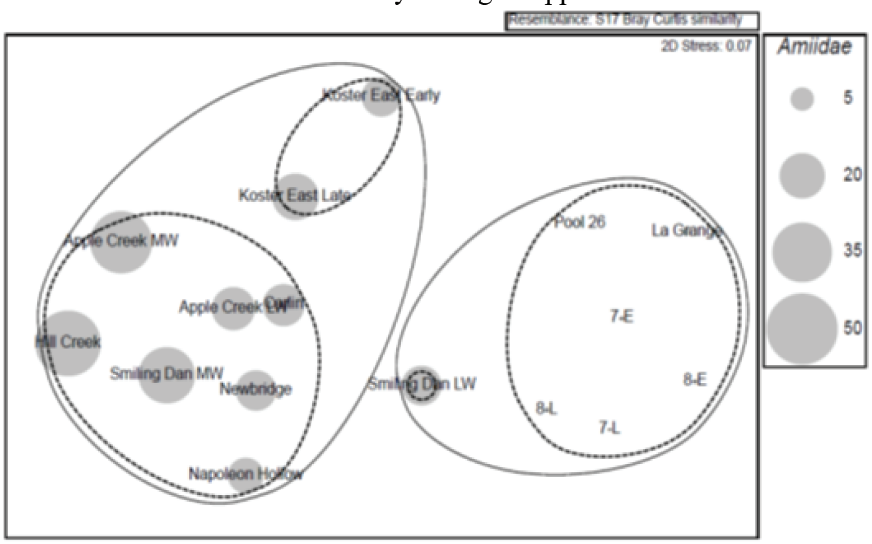
General Research Skills
Identifying the appropriate sample size needed to make interpretations
Presenting scientific research to peers
Interpreting large datasets
Archaeological Skills
Working with archaeological collections
Working with modern zooarchaeological comparative materials
Developing a research design to investigate an archaeological question
Ecological Skills
Identifying and measuring fishes
Working with fish sampling data and conducting analyses
Determining biases associated with fisheries and ecological data
Students were asked to indicate their competence with the following statements on a 5-point Likert scale from 1 = Not at all competent, 2 = Slightly competent, 3 = Somewhat competent, 4 = Very competent, and 5 = Extremely competent.

We used pre- and post-measures of students' perceived ability to execute STEM skills to evaluate student improvements in scientific skills. Items included general questions that asked students to evaluate their abilities in broad scientific competencies, such as identifying a hypothesis when reading scientific literature and identifying independent and dependent variables (Table 1). We also evaluated students' perceptions of discipline specific research abilities such as students' perceived ability to excavate archaeological deposits or work with fish sampling data to conduct an analysis. These survey items were developed by program staff and were specific to program activities. Example items are provided in Table 1.

To evaluate student gains in scientific literacy, program staff developed an 11-item content test. The scientific literacy content questions were written broadly to test each student's general scientific skills, rather than being domain specific. Selected examples of scientific literacy items are presented in Figure 4.

We also developed a program specific content test to measure students' disciplinary and interdisciplinary content understanding. This content test included ten archaeology specific content questions and another ten questions that were specific to

1. All of the following statements about experimental studies are true except for…
    a. Researchers have control over the assignment of treatments to the subjects.
    b. Researchers can use control treatments to account for potential extraneous factors.
    c. They never involve studies where investigators are observing human or animal subjects and recording observations.*
    d. They can be used to test cause and effect hypotheses.
    e. They can be conducted in laboratory settings or in the natural environment.
2. Which of the following is true about an observational study?
    a. Researchers have control over the assignment of treatments to replicates.
    b. These are studies where investigators are observing human or animal subjects and recording observations.
    c. These studies are useful for determining if patterns or statistical relationships exist between variables. *
    d. Researchers can use control treatments to account for potential extraneous factors
    e. These studies occur in a laboratory setting as opposed to the natural environment



3. The above figure is a NMDS two-dimensional representation of differences in archaeological sites and modern fish sampling. The data analyzed are relative abundance (calculated from MNI) of bowfin. The modern fish sampling locations are Pool 26, La Grange, 7E, 7L, 8E, and 8L. All other sites represent archaeological collections. The size of the grey circles surrounding each site is based on the relative abundance of bowfin. Which of the following interpretations can be made about this figure?
    a. Some archaeofaunal collections have large numbers of bowfin represented (>50 individuals); however, several collections have few individual bowfins represented (<5).
    b. Bowfin are only represented by a few individuals in modern ecological monitoring data most likely due to recent overfishing of this species.
    c. The relative abundance of bowfin declines as one moves from Apple Creek MW to Napoleon Hollow.
    d. The relative abundance of bowfin is consistently greater among archaeofaunal collections compared to modern ecological sampling locations. *
    e. Patterns in the relative abundance of bowfin are the result of a few statistical outliers.

Figure 4. Three examples of general scientific literacy content questions to assess knowledge gains. Asterisk indicates correct response.

ecology. The archaeology content questions are provided in Figure 5 and the ecology content questions are presented in Figure 6.

At the end of the program's completion, interdisciplinary student teams finalized their research and developed and presented a scientific poster at an on-campus symposium. These poster presentations allowed an ideal opportunity to evaluate

1. Three features, all at the same horizontal level, are encountered during excavations. Feature A is a large pit bisected by features B and C. Features B and C do not bisect each other. What can you determine from this description?
    a. Past people used features B and C as trash pits.
    b. Past people first excavated the soils to create feature A and subsequently filled it before they created features B and C. *
    c. Past people excavated the soils to create features A and B at the same time.
    d. Past people created features B and C to build a small structure that once covered feature A.
    e. Past people excavated the soils to create features A and C at the same time.
2. Archaeologists use which data class to examine prehistoric evidence of animal overexploitation?
    a. Synchronic data
    b. Latitudinal data
    c. Diachronic data *
    d. Metopic data
    e. Equitability data
3. Processes occurring to an organism after death and during burial affecting preservation is
    a. Analogous structure effect
    b. Phylogeny
    c. Provenience
    d. Commensal relationships
    e. Taphonomy *
4. In a zooarchaeological collection there are a total of 32,211 specimens weighing 1,845.190 g, representing 14.280 kg of biomass. An estimated minimum of 744 individuals from 73 taxa are represented. Which of the following are primary data derived from this zooarchaeological sample?
    a. 32,211 specimens weighing 1,845.190 g *
    b. An estimated minimum of 744 individuals
    c. 14.280 kg of biomass
    d. An estimated minimum of 744 individuals from 73 taxa
    e. 32,211 specimens representing 14.280 kg of biomass
5. Stable isotopes can provide insight into which of the following?
    a. Presence of radio-active waste in an ecosystem
    b. The overall chemical balance of an aquatic ecosystem
    c. Cycles of inundation and drying in a floodplain
    d. Trophic position/long-term diet composition of animals *
    e. Whether an ecosystem is autotrophic or heterotrophic
6. The term that describes the phenomenon in which different processes have similar end effects is
    a. Balanced reciprocity
    b. Gender bias
    c. Equifinality *
    d. Negative evidence
    e. Duel-factor evidencing

Figure 5. Ten archaeological discipline specific content questions to assess knowledge gains. Asterisk indicates correct response.

7. Dr. Hadden is analyzing an archaeological feature containing all fish remains. She discovers all the remains are identified as gar (*Lepsisoteus* sp.). The feature contained 474 gar bones, 469 of these bones are gar scales, 1 right dentary, 1 left quadrate, 1 left hyomandibular, 1 right cliethrum, and 1 left cleithrum. What inferences can Dr. Hadden make about this deposit?
    a. People who formed this feature heavily used gar as a food source.
    b. This deposit is likely a post-contact rather than pre-contact one.
    c. People who formed this feature deposited a gar in it at some point in the past. *
    d. People who formed this feature fished a variety of aquatic habitats including backwater lakes, tributary streams, and in the main channel of a large river.
    e. Pre-contact people used gar in ritualized contexts.
8. Faunal remains from Unit 22 include 82,517 specimens weighing 3,270.281 g. Sixty-four vertebrate taxa and one shrimp are represented by an estimated minimum of 1,872 individuals. Which of the following are secondary data derived from this zooarchaeological sample?
    a. 82,517 specimens
    b. 3,270.281 g
    c. 64 vertebrate taxa
    d. The identification of shrimp remains
    e. Estimation of 1,872 minimum number of individuals. *
9. Dr. Hadden is analyzing an archaeological feature containing a few fish taxa. Nearly all fish remains recovered are identified as bowfin (*Amia calva*) and bullhead catfish (*Ameriurus* sp.). What interpretation would be the most appropriate for Dr. Hadden to make?
    a. People in the past fished the main channel of a nearby river that likely lacked aquatic vegetation.
    b. People in the past fished nearby streams with swift currents and high levels of dissolved oxygen.
    c. People in the past most likely captured these fishes with harpoons.
    d. People in the past most likely captured these fishes with cast nets.
    e. People in the past fished in nearby area with low levels of dissolved oxygen. *
10. Presently, there are many dolphins, alligators, and sharks that reside in Georgia estuaries; however, zooarchaeologists rarely identify these species among archaeological deposits along the Georgia coast. Which of the following interpretations best accounts for the lack of these taxa in archaeological deposits.
    a. People in the past did not use or eat these animals.
    b. People in the past used these animals but butchered them at the location where they were killed leaving no trace of these animals at archaeological sites.
    c. These animals did not occur on the Georgia coast in the same frequency in the past as they do in the present.
    d. People in the past avoided these animals or viewed their consumption as taboo.
    e. All of the above interpretations are possible explanations for the lack of these animals in archaeological deposits from the Georgia coast. *

Figure 5. Ten archaeological discipline specific content questions to assess knowledge gains. Asterisk indicates correct response (continued).

students' ability to communicate scientific concepts. Selected guests, many of whom were research scientists, were asked to evaluate each teams' presentation of their research using a 10-item rubric organized in three groupings: organization, delivery, and substance. The rubric included a 5-point scale with one being the lowest score and five being the highest (Figure 7). Guests evaluating the students' work spoke with each research team and reviewed their posters to make their assessment.

1. Great Rivers are a subset of rivers with which of the following characteristics?
    a. Stable flows interrupted by random floods that reset the ecological community
    b. Water quality and biotic communities in near pristine condition
    c. A large floodplain that is subject to predictable annual flooding for a significant duration *
    d. Defined exclusively by size and flow rate
    e. Stable flows with minimal annual variation relative to other rivers
2. What is the common name of this fish?

    a. Bigmouth buffalo
    b. Shortnose gar *
    c. Paddlefish
    d. Smallmouth buffalo
    e. Bowfin
3. What is the common name of this fish?

    a. Bullhead catfish
    b. Bullhead minnow
    c. Channel catfish *
    d. Yellow bullhead
    e. Shovelnose sturgeon
4. What is the common name of this fish?

    a. Gizzard shad *
    b. Emerald shiner
    c. Freshwater drum
    d. White bass
    e. Bluegill
5. Aldo Leopold is remembered for
    a. Introducing the land-use ethic and the foundations wildlife management
    b. Popular writing about nature
    c. Developing the early foundations of quantitative fisheries ecology
    d. Both A and B *
    e. A, B and C

Figure 6. Ten ecological discipline-specific content questions to assess knowledge gains. Asterisk indicates correct response.

6. For large-floodplain rivers, which of the following correctly characterizes navigation dams, levees, land-use change in the floodplain, and sediment loading, as either sources of habitat loss or sources of habitat degradation?
    a. Navigation dams and levees are habitat loss; sediment loading and land-use change in the floodplain are habitat degradation
    b. Levees and land-use change in the floodplain are habitat degradation; navigation dams and sediment loading are habitat loss
    c. Navigation dams and sediment loading are habitat degradation; levees and land-use change in the floodplain are habitat loss *
    d. Navigation dams and levees are habitat degradation; land-use change and sediment loading are habitat loss
    e. Navigation dams, levees, land-use change in the floodplain, and sediment loading are all combinations of both habitat loss and habitat degradation
7. According to Eugene Odum, an ecosystem is _______ and ecology is _______
    a. More than the sum of its parts – a distinct discipline rather than a subject within the discipline of biology *
    b. The cradle for any life form – the stage on which biology is played
    c. The non-biotic environment that is habitat – the study of habitat's effects on organisms
    d. Totally huge, so huge you can't imagine – the best thing that's happened ever, EVER!
    e. A type of superorganism composed of synergistically interacting species – the study of synergism
8. Which of the following elements is most important when planning a sampling or monitoring design that will be comparing and contrasting data collected from multiple locations at multiple points in time?
    a. Standardization of methods *
    b. Accuracy of measurements
    c. Logistic feasibility of methods
    d. Adaptability of methods for different locations and researchers
    e. Equipment maintenance
9. Stable isotopes can provide insight into which of the following?
    a. Presence of radio-active waste in an ecosystem
    b. The overall chemical balance of an aquatic ecosystem
    c. Cycles of inundation and drying in a floodplain
    d. Trophic position/long-term diet composition of animals *
    e. Whether an ecosystem is autotrophic or heterotrophic
10. Which of the following accurately describes how Nonmetric Multidimensional Scaling (NMDS) and Analysis of Similarity (ANOSIM) are used to examine community structure?
    a. NMDS tests whether community structure differs among groups and ANOSIM illustrates the similarity among groups
    b. NMDS is used to transform community data prior to conducting ANOSIM
    c. ANOSIM tests whether community structure differs among groups and NMDS illustrates the similarity among groups*
    d. NMDS is used to examine community composition (e.g., presence/absence of species) whereas ANOSIM is used to examine the relative abundance of species
    e. ANOSIM is used to determine whether community data should be transformed prior to analysis with NMDS

Figure 6. Ten ecological discipline-specific content questions to assess knowledge gains. Asterisk indicates correct response (continued).

		1	2	3	4	5	Score
	Abstract and title	Title and/or abstract do not coordinate with presentation.	Title is too long or uninformative. Abstract does not provide an accurate synopsis of the presentation. No clear purpose, methods, and conclusions stated.	Title is appropriate. Abstract provides a relatively accurate synopsis of the presentation but no clear purpose, methods, and/or conclusions.	Title is appropriate. Abstract provides an accurate synopsis of the presentation with clear purpose, methods, and conclusions stated.	Title is appropriate and generates interest. Abstract provides an accurate synopsis of the presentation with clear purpose, methods, and conclusions stated.	
	Content	Irrelevant, uninformative material. Difficult to follow.	Choppy sequence of information, no clear and definitive sections. Still a little difficult to follow.	Sequence of information is ok. Sections are labeled, but may not be very clear.	Sequence of information is logical. Sections are clearly labeled (poster) or the material flows well as presented.	Sequence of information is impeccable and easy to follow. Sections are clearly labeled (poster) or the material flows effortlessly as presented.	
	Aesthetics/ readability (visually appealing)	Not visually appealing. Cluttered or sloppy. Difficult to read, text size is too big or too small.	Acceptable color scheme and appearance but difficult to read.	Readable but color scheme, text, and/or graphics were distracting.	Readable with pleasing use of colors, text, and graphics.	Excellent visual appeal, shows creativity. Easy to read, all text is an appropriate size. Colors coordinate and fonts are uniform.	
	Presentation style and quality	Unkempt appearance, difficult to understand (too quiet/slurred speech). Nerves or mannerisms are distracting. Either lack of visuals or inappropriate use of visuals.	Appropriate appearance. Nerves or mannerisms are distracting. Would have benefited from more visuals (figures, tables, images).	Appropriate appearance. Nerves are apparent in speech but not very distracting. Visuals are adequate.	Appropriate appearance. Clearly articulated information. Visuals are adequate.	Professional in appearance and manner. Clearly and concisely articulated information. Speaker kept your attention; and spoke with confidence and enthusiasm. Visuals are appropriate, meaningful and enhance the information.	
	Content level of poster or presentation	Content is over simplified or too complex for conference. No background information. Used a lot of undefined jargon.	Content is over simplified or too complex for conference. Limited background information. Used a lot of undefined jargon.	Content is appropriate for the conference. OK amount of background information. Limited amount of jargon.	Content is appropriate for the conference. Good amount of background information. Used some jargon, but defined it.	Content is appropriate for the conference. Perfect amount of background information. Either no jargon, or small amount that was defined.	

	continued	1	2	3	4	5	Score
Substance	**Objective and introduction**	No clear objective. No introduction.	Had an introduction but didn't address the objective.	Had an introduction with objective present but not clearly stated; buried in text.	Good introduction, objective was present and clearly stated.	Nature and rationale for the research are clear. Explicit objective, includes heading of "objective", "aim", "goal", etc.	
	Study design/ methods	No explanation of study design and methods.	Brief mention of study design and methods. Methods seem unjustified or unreliable.	Brief mention of study design and methods. Methods seem appropriate.	Study design and methods were appropriate and explained well.	Great explanation of study design. Methods are appropriate and justified for the research.	
	Results	No results were given.	Visually presented but not explained.	Visually presented but skimmed over quickly, leaving the audience confused.	Visually presented and explained, but still slightly confusing.	Visually presented; thoroughly explained in an easy to understand manner.	
	Conclusions	No conclusions.	Stated conclusions but they are not scientifically justified or do not address the research question.	The conclusions are stated and have some scientific justification. May not explicitly address research question (s).	The conclusions are scientifically justified, and addresses the research question (s).	The conclusions are thoroughly explained, scientifically justified, based on data, addresses the research question (s), and recognized the limitations and strengths of data.	
	Knowledge and accuracy of information	Presenter was not prepared. Outdated material with no use of recent literature. Presenter conveyed a weak understanding of the material. Unable to answer questions.	Presenter was not prepared. No use of recent literature. Presenter struggled with content of the presentation. Answers to questions were vague and unclear.	Presenter seemed somewhat prepared. Information was up-to-date with some use of recent literature. Presenter conveyed some understanding of the material. Gave reasonable answers to questions.	Presenter researched topic and was adequately prepared. Information was up-to-date with use of recent literature. Presenter conveyed a clear understanding of the material. Gave good answers to questions.	Presenter thoroughly researched topic and was completely prepared. Information was up-to-date with extensive use of recent literature. Presenter conveyed complete understanding of the material. Gave excellent, practical, succinct answers to questions.	
						Total points:	50

Additional comments:

Figure 7. Rubrics used to assess each interdisciplinary research team's final poster. Rubric used and reproduced courtesy of the Mississippi River Research Consortium.

Combined, these tools formed the program's summative assessment used to evaluate the five learning objectives we had for participating students.

Results

The formative assessment related to student educational outcomes indicates that each student cohort gained confidence in their progress towards their final research project (Figure 8a), in their ecological skills (Figure 8b), and their archaeological skills (Figure 8c) over the course of the program. Throughout the program, students demonstrated some wavering in their confidence levels related to these three items, but overall, students experienced strong growth in their perception of their overall confidence to conduct their research, as well as related discipline and non-discipline skills.

For the summative assessment, we measured significant gains in all five objective areas in all three years of the program. Students demonstrated significant gains in critical thinking as measured through our assessment rubric.

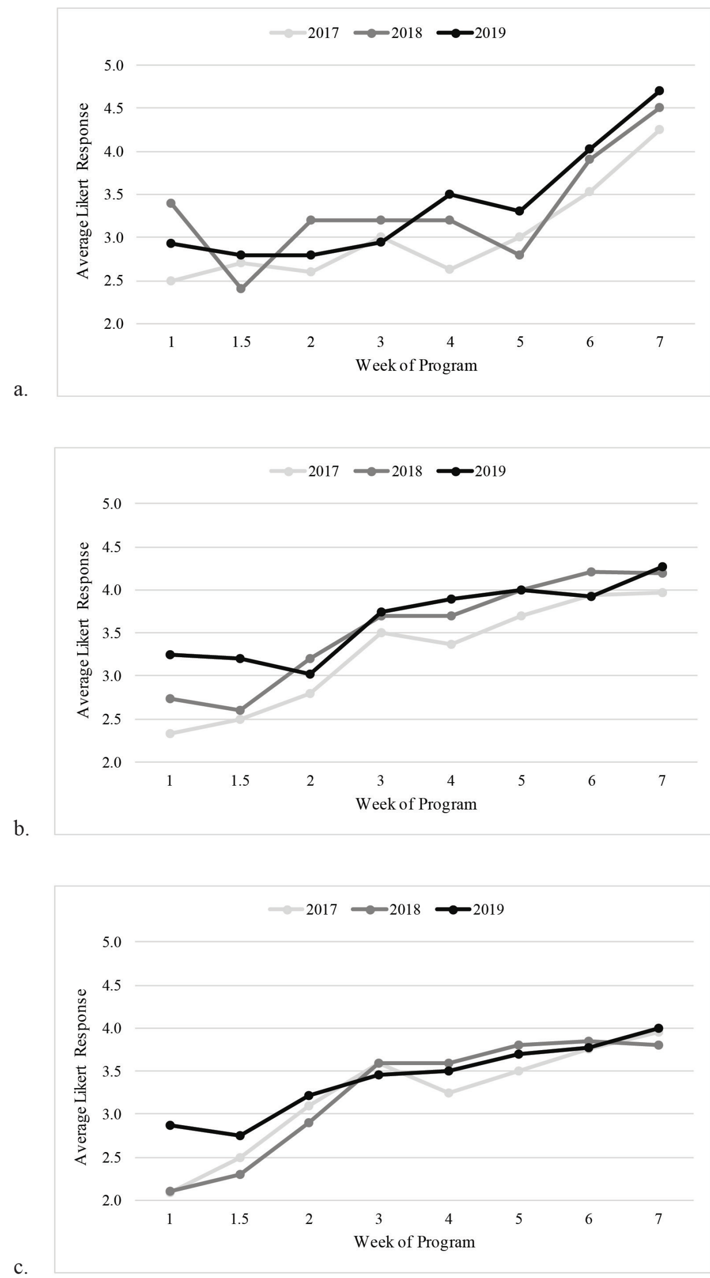


Figure 8a-c: The following figures visually track student responses to confidence items for each years' cohort. Two surveys were administered in week one (1 and 1.5). a) Tracks the average of students' 5-point Likert responses to the question "How confident are you with your progress toward your research project?" for each years' cohort; b) Tracks the average of students' 5-point Likert responses to the question "How confident are you with your ecological skills?" for each years' cohort; c) Tracks the average of students' 5-point Likert responses to the question "How confident are you with your archaeological skills?" for each years' cohort.

Table 2. Pre- and Post-Program Results of the Critical Thinking across the Curriculum Assessment Rubric.

	Pre-Survey 2017		Post-Survey 2017		Pre-Survey 2018		Post-Survey 2018		Pre-Survey 2019		Post-Survey 2019	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
Analyzing information; data, ideas, or concepts	1.65	0.49	2.85	0.49	1.50	0.51	3.35	0.49	1.70	0.47	3.35	0.49
Applying formulas, procedures, principles, or themes	1.05	0.22	2.80	0.62	1.35	0.49	3.05	0.69	1.25	0.44	3.30	0.47
Presenting multiple solutions, positions or perspectives	1.35	0.49	2.90	0.85	1.65	0.49	3.45	0.51	1.35	0.49	3.70	0.47
Drawing well-supported conclusions	1.30	0.47	3.05	0.39	1.35	0.49	3.55	0.51	1.20	0.41	3.40	0.60
Synthesizing ideas into a coherent whole	1.10	0.31	2.65	0.67	1.35	0.49	3.70	0.47	1.35	0.49	3.45	0.51

Numerical values from 1 to 4 are assigned to the rubric's levels of achievement with 1 as beginning, 2 as developing, 3 as competent, and 4 as accomplished. All pre-survey and post-survey means significantly differ from one another at $p < 0.001$.

Each year, program staff perceived that students achieved significant gains in all five components of the Critical Thinking across the Curriculum rubric (Table 2).

Students reported increases in their perception of their general scientific skills and discipline specific skills on the 26-item survey from the beginning to the end of the program (Table 3). For all cohorts, students had a higher perceived ability in their general scientific skills compared to their discipline specific skills. This perceived higher ability in general scientific skills persisted to the end of the program compared to discipline specific skills for all cohorts, though students did experience greater growth in

Table 3. Pre- and Post-Program Self-Report Perceived Science, Archaeology, and Ecology Skills.

	Pre-Survey 2017		Post-Survey 2017		Pre-Survey 2018		Post-Survey 2018		Pre-Survey 2019		Post-Survey 2019	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
Perceived general science skills	2.77	0.82	4.40	0.45	2.96	0.68	4.53	0.29	2.90	0.86	4.33	0.44
Perceived archaeology skills	2.00	1.05	3.94	0.91	2.00	1.00	4.24	0.75	2.01	1.07	4.11	0.76
Perceived ecology skills	1.88	0.61	4.23	0.53	2.13	0.91	4.50	0.62	2.22	0.91	4.25	0.61

Table 4. Pre- and Post-Program Scientific Literacy Content Test.

	Pre-Survey		Post-Survey		
	Mean	St Dev	Mean	St Dev	*p* value
2017	47%	0.18	72%	0.16	0.003
2018	37%	0.18	75%	0.07	<0.001
2019	39%	0.15	55%	0.12	0.009

Table 5. Pre- and Post-Program Discipline Specific Content Test.

	Pre-Survey		Post-Survey		
	Mean	St Dev	Mean	St Dev	*p* value
2017	44%	0.13	64%	0.13	0.002
2018	35%	0.07	70%	0.07	<0.001
2019	40%	0.05	63%	0.08	<0.001

their perceived discipline specific skills through the course of the program.

Each year, students, in aggregate, demonstrated significant gains on the 11-item, program-developed scientific literacy content test (Table 4) with aggregated pre-program scores ranging from 37% to 49% and post-program scores ranging from 55% to 75%. Students also demonstrated significant gains in the 20-item content specific test from the start to end of the program (Table 5). On the discipline specific content test, each year, archaeology students had strong gains in the ecological content and vice versa.

For the science communication assessment, student interdisciplinary teams received high percentages of the available points on the poster presentation rubric. During each year's assessment, student groups received an average of 89% or above of the available points.

Discussion

Other disciplines have undertaken studies to better understand student learning outcomes associated with field-based research experiences as well as informed models to structure field-based learning programs (Cartrette and Melroe-Lehrman 2012; Cooper et al. 2019; Flaherty et al. 2017; Graham et al. 2013; Jacobson et al. 2015; Mogk and Goodwin 2012; Munge et al. 2018; National Research Council 2014; Richards et al. 2012; Sheppard et al. 2010; Whitmeyer and Mogk 2009). The education research we present contributes to the documentation of student learning outcomes associated with field-based research. Our primary goal for presenting this research is to help others develop a means to evaluate their field-based learning programs. Further, these data may potentially inform variations on the traditional field school instructional model.

The program we offered was distinctive from many field schools. We received NSF funding to design an evaluation strategy that collected data to demonstrate that our programming allowed students to achieve the stated learning objectives. This funding gave us the opportunity to partner with an educational evaluator, design strong assessment instruments, implement these instruments, and analyze and summarize the student learning data. Such steps may not be achievable for field school directors given limitations in funding and time constraints. The majority of the evaluation effort did go toward consultation with the evaluator in year 1 for instrument development. In subsequent year, the evaluator's effort mostly was dedicated to data analysis and summary. Once our team designed the evaluation tools, which were finalized prior to student programming, implementation was relatively effortless and did not distract from student learning or instruction. Pre- and post-assessment instruments took approximately one hour for the students to complete and a couple of hours for the evaluator to score and analyze. The weekly formative assessment was easily set up and scheduled using the online survey software. This software also presents the data in a summarized form. Though the evaluation we designed and administered likely is more extensive than what may be viewed as necessary, components of this evaluation could be implemented during field school without excessive demands on the director's or staff's time.

The evaluation data provided valuable student feedback that helped us improve the program from week to week and year to year. The weekly formative assessment especially was beneficial to our students and us as the program directors. We advocate for directors to consider a formative assessment as a component of any field school and field-based learning program where possible.

These weekly surveys—asking students to evaluate their perceptions of their discipline skills and programmatic progress—provided feedback we could use to strengthen learning supports for students. In all three years of programming, we saw a shift in student confidence at certain points during the program (Figure 8a). Students went from being somewhat confident that they could do the work we presented to them, shifted to being less confident, and then shifted to being very confident in their skills by program's end. Receiving this type of feedback throughout the program made us aware of those points when students benefited from positive feedback. For example, during weeks 4 and 5, we intentionally highlighted all the skills the students had acquired, the things that they had accomplished, and how much they had learned. We felt that this step allowed them to more fully see all that they had achieved during a short time, giving them the confidence needed to complete their final research projects. These formative assessments helped us provide confidence boosters at these critical points.

Similar formative assessments can be administered, with relative ease, over the course of field schools. Such data should help field directors understand those points in the field school when students experience shifts in their confidence. Importantly, program specific items and open-ended questions also allow students to anonymously disclose aspects of learning where they may feel they need additional support or issues they may be experiencing that distract from learning and the overall quality of the program (Clancy et al. 2014; Meyers et al. 2018; VanDerwarker et al. 2018).

Several of the components we added to the REU program benefited student learning and may be educational aspects field directors may consider for their field schools. The facilitated critical reflections were a valued component of our field program. Critical reflections gave students the opportunity to discuss, synthesize, and put words to what they learned helping them more deeply understand new knowledge and skills (Hatcher and Bringle 1997; Ryan and Ryan 2013). With critical reflection discussions, we guided students through understanding the context of when they would apply the skills they learned, how the results of data collection could be applied, and how data could be used to address hypotheses. Facilitating critical reflection sessions that provide the opportunity for students to communicate the skills they learned and the context in which they have and would implement that skill may help students leave their field school with a more comprehensive understanding of field archaeology. Although we believe the facilitated reflection sessions were a strong component of the program, further research and testing is needed to more thoroughly document the effects of these sessions on student learning in the field school context.

When we designed this REU program, we heavily used an archaeological field school model to structure the program because an equivalent, immersive course is not standard in ecological undergraduate education. After we had clearly identified the student learning objectives for this program, we realized that with the current field school model—six to eight weeks of intensive archaeological field training (Baxter 2009)—we might not achieve our programmatic learning goals. We had to develop a program that would scaffold, guide, and mentor students through the entirety of the research program and that would not exclusively focus on learning and practicing field methods. In so doing, we shortened the time students spent conducting archaeological field methods (Figure 1). We added components to the program that allowed students to apply both field and laboratory skills to understand how data derived from each setting is used in the context of research. We present our approach to field-based education as one that prioritizes students acquiring fundamental research skill: inquiry-based and critical-thinking skills and the application of those skills. We emphasized these skills over discipline specific skills and application. Though this model does fall on one extreme end of the spectrum of potential field school experiences, there may be some approaches to this form of field-based instruction that field directors may consider incorporating into their programs.

Field school directors may consider intentionally incorporating mechanisms for students to develop, conduct, analyze, and disseminate research that builds upon the overarching research agenda of the field school. If possible, student research should take place concurrently with the field school. Incorporating student-driven research projects within a field school can help students gain the critical-thinking and inquiry skills that will prepare them for a career as an archaeologist. In this way, field directors position students to engage in a more authentic research experience compared to what students might gain through a traditional field school approach or through a course-based research experience. As other researchers have noted, this approach helps students see themselves as someone who has the ability to do science and does science, not just someone who helps support scientific research (Linn et al. 2015; Seymour et al. 2004; Sorensen et al. 2018).

Field school directors may be hesitant to incorporate undergraduate research into their field school teaching model. The traditional field school teaching model has not necessarily trained students to conduct archaeological research, but rather, has placed an emphasis on students acquiring and practicing field-based skills in preparation for field technician jobs (Walker and Saitta 2002). The program we offered guided students through a more thorough understanding of how scientists, both archaeologists and ecologists, collect data, analyze those data, and derive meaningful interpretations about past human-environmental interactions. We see these skills as a step towards creating more competent scientists with the foundation to refine their field skills through participation in future field courses or when students gain employment.

We believe that the positive learning gains the students achieved from our approach to field-based learning instruction provides some evidence that students can thrive in this model. Field school directors may want to consider assessing their current instructional model to incorporate elements that support student research. Our assessments indicated that this model led to significant gains in students' critical-thinking skills, scientific literacy, discipline specific content knowledge, and scientific communication skills. This model clearly supported the proposed student-learning objectives and may be an ideal model for field-based programs with similar objectives.

Though we advocate for a field school model that positions students to conduct their own research, we recognize that other field schools may be using a model similar to the one we developed for this REU program. Unfortunately, there has been little empirical research and discussion on field school pedagogy (see Mytum 2012a) and as such, we do not know if a more student-centered research model is common or if field school directors emphasize students acquiring field skills as the primary learning objective (Walker and Saitta 2002). We recognize that different field school directors may have a unique set of learning goals for their students and our field-learning model may not support all learning goals. Surveying the discipline to document current teaching models and associated learning objectives for field schools is a promising area for future research and the findings from such research may help us refocus the way we structure future field-based learning programs for students.

Educators increasingly face pressure to justify field schools and other courses that include significant expenses and liabilities as federal, state, and university budgets tighten (Boytner 2012; Colley 2012). Though field directors must balance the need to produce scholarly research from the data collected during their field schools and the education goals they have for their students (Walker and Saitta 2002), forming programs that prioritize student learning opportunities while documenting the learning that does occur should become standard practice. These data justify the value of field-based learning, as well as the field-school approach and requirement that archaeologists have taken towards undergraduate education. Having clear documentation of the program's student learning objectives and associated outcomes helps promote the need to continue field schools and other field-based learning opportunities for students.

Conclusions

The program we designed helped students gain significant increases in all five of our learning objectives. As field directors, we found that both the formative and summative assessment of the program provided valuable feedback to us as educators, but these data are also useful in justifying the need for undergraduate field learning, as well as conveying student outcomes, both positive and negative. From our observations, providing students the opportunity to participate in all aspects of research helped them gain skills that will prepare them for success as future scientists and archaeologists. Further, the facilitated critical reflections helped students have a more thorough understanding of the context of the research skills they acquired. Though this program was not a field school, many aspects of our REU program can be modified and adapted for future field schools and other field-based learning programs for undergraduate students.

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