CHAPTER 6

Authenticating Interdisciplinary Learning through a Geoscience Undergraduate Research Experience

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Abstract The geosciences may be the most interdisciplinary of all STEM disciplines. Earth system sciences and the complex sub-systems of the cryosphere, the atmosphere, the lithosphere, the biosphere, and the hydrosphere subsume all human activity and are critical to every aspect of life on Earth. Therefore, by their very natures, the geosciences are rife with copious interdisciplinary strands and themes that are waiting to be explored by students from a wide range of STEM disciplines. With studies highlighting the benefits of authentic undergraduate research experiences, an innovative program was designed to have STEM students actively and collaboratively construct their knowledge of the geosciences. Results indicate that the geoscience research experiences increased the students' understanding of the relevancy of their interdisciplinary study to society.

Keywords Interdisciplinary • Geosciences • Remote sensing • STEM • Undergraduate research • Underrepresented minority students

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Globalization and the need to address the diverse complexities and maladies of an ever-advancing yet ever-shrinking world are the main drivers behind the imperative for interdisciplinary learning at this critical juncture of the twenty-first century. Students now need not only to think, navigate, and advance on the local scale, but also to be equipped with the knowledge and the skills necessary to confront global challenges. These challenges in science, technology, engineering, and mathematics (STEM), medicine, economics, and a whole host of other disciplines are no longer restricted to and confined within rigid disciplinary borders. Indeed, historical disciplinary borders are now not only blurred, but in some cases they have also been torn down. Disciplines (and knowledge for that matter) are no longer isolated and siloed; they are systematic, integrative, and interdisciplinary in nature and scope. It is in this milieu of interdisciplinary renaissance and revolution that individual disciplines fulfill their true creeds, identities, and purposes. The complete overcoming of STEM challenges is wholly predicated on the complete understanding of the disciplinary sub-components of these challenges and then on how these sub-components relate to, differ from, and influence each other. This is the essence of interdisciplinary learning, knowledge, and authentication.

Twenty-first century challenges will require bold, innovative solutions that are knitted and seamlessly interwoven in the fabric of connective, synthesized learning that draws upon knowledge from across the disciplines. These novel solutions will come from critical thinkers who are flexible and reflective students of interdisciplinary learning and who grasp and are cognizant of the interplay between—and the dependency within—disciplines as problem-solving is being conducted. Philosopher Karl Popper understood this well. He emphasized the assertion that since problems are unbounded by disciplines, so too must their solutions be.[1] However, for these solutions to be interdisciplinary authentic, Biox and Duraising argue that the student problem-solvers: (1) *be well grounded in the disciplines*: show rigorous understanding and use of disciplinary tools, perspectives, and approaches, (2) *show critical awareness*: be mindful of the purpose and the means by which the disciplines have been brought together—the discipline's potential contributions and limitations, and (3) *exhibit advanced understanding*: demonstrate that they have developed a new model, perspective, insight, or solution that could only be possible by integrating more than one discipline.[2] As these students engage in authentic interdisciplinary learning, they not only increase cognitive abilities[3] and problem-solving skills, but they also acquire new perspectives, engage in deeper more comprehensive probing and understanding of issues and problems, devise alternate solutions, and start on their way to becoming lifelong learners. Moreover, interdisciplinary learning also allows them to see global and local challenges through a different set of lenses. These interdisciplinary lenses enable them to analyze, synthesize, and assimilate pre-existing ideas with new critical thinking abilities to develop new, transformative knowledge and opportunities. To this end, as described below, geoscience research (an ideal STEM platform for interdisciplinary learning) was used as a catalyst for interdisciplinary learning among undergraduate students at the City University of New York.

Promoting the Interdisciplinary Nature of the Geosciences

A plethora of recent studies gives both evidence of and solutions to the nation's STEM crisis.[4] Perhaps unlike any other STEM discipline, geoscience and its related subfields (e.g., environmental earth science, atmospheric science, oceanography, hydrology, geology, geochemistry, and geophysics, among others), are uniquely and inherently interdisciplinary. However, they are also fraught with many of the problems—from climate change impacts and natural disasters to renewable energy sources—that still need twenty-first century solutions. The geosciences, therefore, offer both challenges and opportunities that range from the neighborhood scale to the global scale. Interdisciplinary ingenuity is needed to tackle these challenges and to exploit, advance, and realize the opportunities they provide.

For these endeavors, students must be trained and equipped with interdisciplinary tools and skills. A National Science Foundation (NSF) Research Experiences for Undergraduates (REU) grant was used in part to demonstrate that students who are polarized and isolated in their individual STEM disciplines can be trained and equipped to think, act, and produce in an interdisciplinary manner via structured engagement in a high-impact, best practices-driven undergraduate geoscience research program. This program affords students the opportunity to participate in state-of-the-art satellite- and ground-based remote sensing of the cryosphere, the lithosphere, the hydrosphere, the biosphere, and the atmosphere.

The Interdisciplinary Geoscience Undergraduate Research Experience

New York City College of Technology (City Tech) was awarded two NSF REU grants from 2008 to 2015. The REU program was intentionally designed to encourage and to foster interdisciplinary learning, particularly in the geosciences through satellite- and ground-based remote-sensing projects. REU scholars were actively engaged in full-time research for nine weeks in the summer and one day per week in the fall and spring semesters.

The learning outcomes for the REU scholars were established by using the benefits gained statements from the evaluation instrument: Undergraduate Research Student Self-Assessment Survey.[5] These indicated gains are potentially portable within and beyond their STEM disciplines. REU scholars in the one-year research program were expected to report gains in the following four areas:

1. *Thinking and working like a scientist*
   REU scholars will have a clear understanding of how the scientific disciplines are connected and of how scientific research is done. They will be able to comprehend and apply problem-solving and analytical skills to their research. Furthermore, their knowledge of the geosciences will be expanded and strengthened.
2. *Personal and professional gains related to research work*
   REU scholars will display confidence conducting research, working collaboratively with other researchers, and excelling in future science courses.
3. *Becoming a scientist*
   REU scholars will have the skills and ability to work independently and to reflect and display ownership of their own research.
4. *Skills*
   REU scholars will have the ability to write scientific papers, explain their research to others in the field and to broader audiences through research presentations, prepare scientific poster presentations, articulate the relevance of their research, and know and understand the existing body of research relevant to their topic.

The REU program design supported the interdisciplinary learning of geoscience concepts in four areas of the research process: (1) mentoring, (2) mini-courses and seminars, (3) field experiences, and (4) conference participation.

(1) *Mentoring*

The REU program implemented a structured mentoring paradigm that consisted of an interdisciplinary team. Each REU scholar was affiliated with a team that involved a faculty research scientist, a post-doctoral research scientist, a graduate student, and a high-school student. The faculty research scientist designed the research project with input from the post-doctoral research scientist and the graduate student. Although they were all working in the same laboratory, each person differed in expertise. Therefore, an interdisciplinary team culture was created. Resources, expertise, and experiences were shared and a community of practice was formed. As a result, each REU scholar benefited from the relationships developed. Additionally, the REU scholar also became a mentor to a high-school student who also benefitted from the interdisciplinary team structure.

(2) *Mini-Courses and Seminars*

REU scholars come to the REU program with varied educational skill sets, and they often do not have the necessary background for research, especially in the geosciences. To prepare them with the tools needed for satellite- and ground-based remote-sensing research, the REU program organized four crucial mini-courses: MATLAB, remote sensing, geographic information systems (GIS), and basic statistics. These mini-courses were offered during the second and third weeks of the nine-week summer program.

MATLAB: This mini-course introduced students to the fundamentals of MATLAB programming. Students were taught how to use MATLAB as a tool to study and analyze remote-sensing data and to manipulate basic algorithms for remote-sensing applications. The software's statistical, graphics, mapping, and visualization tools were applied to real-time data sets from both satellite- and ground-based measurements.

Remote sensing: This mini-course provided students with the basic knowledge necessary to begin to understanding the key fundamentals of the science of environmental remote sensing and its related geoscience applications. Students learned about environmental measurements obtained from space platforms and from the variety of other platforms that are used for remote-sensing applications. They were introduced to polar orbiting satellites, geostationary satellites, active and passive systems, the atmosphere and atmospheric sounding techniques, interferometric and LIDAR systems, image processing, and radiative transfer.

Geographic information systems (GIS): Essential GIS concepts and techniques, including GIS database queries, tabular data manipulation, spatial and attribute data editing, data presentation via maps and charts, map layers, area measurement, scale, and symbology were taught. The relevance and connectivity of GIS to remote sensing were highlighted.

Basic statistics: In this mini-course, basic descriptive statistics were taught with special emphasis on correlation and linear regression techniques using real world applications. Taken together as an interdisciplinary package, these mini-courses provided the REU scholars the skills and the basic knowledge needed for their geoscience research projects.

Seminars: Another important component of the REU program is its seminars. Faculty members participating in the REU program were renowned scientists from the Remote Sensing Science and Technology Center (CREST) located at the City College of New York. CREST is a National Oceanic and Atmospheric Administration (NOAA) research facility. NOAA-CREST conducted a weekly seminar series (at the City University of New York and all partner institutions), by inviting geoscience experts—the majority of whom were from NOAA line offices—to present research projects that were congruent to NOAA-CREST sciences. These seminars were largely attended by NOAA-CREST scientists, their graduate and undergraduate students, and the research community within each campus. The seminar series provided students with a broader perspective of their research projects, and the seminars helped to initiate and to strengthen research collaborations. Moreover, they also increased scientific horizons beyond the students' individual research areas.

(3) *Field Experiences*

In order to establish geoscience research career pathways, to expand student exposure to remote sensing beyond the campus, and to promote the attainment of graduate degrees, field experiences were organized at different research and educational sites. The opportunities were arranged so that the REU scholars would have an opportunity to tour the facilities and to meet scientists with interdisciplinary academic backgrounds at the laboratory.

These field experiences inspired the students to keep aspiring toward STEM success, and they provided the students with a vision of what they can become after they graduate from college. The students were exposed to and interacted with scientists who had degrees and interdisciplinary experiences that supported and advantaged them in their current positions.

Without establishing field and site partnerships, exposing the REU scholars to careers beyond their own disciplines would not have been possible. The sites below provided the following benefits:

- *The Brookhaven National Laboratory*—Weather balloon launches at the National Weather Service were observed. These radiosonde launches were interdisciplinary in nature, as they involved teams of scientists with varying STEM degrees who used the collected data to study various aspects of the troposphere.
- *The National Center for Weather and Climate Prediction*—The center provided REU scholars with lectures and tours. Opportunities to interact with the operational scientists who were on duty monitoring and predicting atmospheric and oceanic dynamics provided an engaging experience. These experiences were interdisciplinary as meteorologists, oceanographers, and computer scientists converged to study and share their integrative, interdisciplinary knowledge about the Earth system in real-time, operational, and collaborative sessions.
- *The American Museum of Natural History*—Climate change and astronomy exhibits were highlighted at the museum. Informal, interdisciplinary learning occurred as resident scientists helped students to make the system-wide connections and feedback mechanisms between the different inter-connected strands of the geosciences.
- *The Cary Institute of Ecosystem Studies*—Forums on translational ecology and hydrology were provided. Interdisciplinary hydro-ecological lessons were taught by the geoscientists and the researchers at the Institute.
- *The Solar Panel House*—Demonstrations of how solar energy can be used to provide 100 % of the energy needs of a house were presented. Mechanical and civil engineering faculty demonstrated how seamlessly the interdisciplinary relationships between engineering and the geosciences are with regards to the Earth's ultimate energy source (the sun), renewable energy, economics, and living conditions.

(4) *Conference Presentations*

The culminating interdisciplinary geoscience component of the REU program is the presentation of the students' research projects at national and regional geoscience and STEM conferences such as the American Geophysical Union (AGU), the American Meteorological Society (AMS), the NOAA Educational Partnership Program, the Louis Stokes Alliance for Minority Participation, the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers, the National Science Foundation (Emerging Researchers National Conference in STEM), and the Mathematical Association of America (MAA). This additional level of exposure and scholarly validation is extremely valuable and beneficial to the undergraduates, because it allows them to participate in the geoscience realm in ways that authenticate their interdisciplinary experience. They feel a sense of purpose and belonging as they join, exchange, and network with fellow students and scientists. Vistas of graduate school and career options become open, and the REU scholars are inspired to become the future geoscientists that they could not envision being before joining this interdisciplinary program.

REU Student and Faculty Participants

The REU geoscience research program encourages students majoring in any STEM discipline to apply. With a shortage of students majoring in the geosciences, the premise of the research opportunity is to create awareness of how interdisciplinary the geosciences really are and to provide a pathway for students to acquire sufficient geoscience knowledge that they may afterward apply to the geoscience workforce with their STEM majors. The REU scholars were recruited and selected from several of the twenty-three campuses of the City University of New York. Students were primarily in their junior or senior year. However, a few exceptional sophomores from community colleges and two-year programs have participated in the program because of their prior research background. The students must also be either US citizens or permanent residents with a grade point average of 3.0/4.0 or above. Being a geoscience major or having a geoscience background is not a requirement for the REU program.

Since the awarding of the grant in 2008, a total of 78 students have successfully completed the year-long REU program. Of the 78 students, 82.1 % (64) majored in a STEM discipline other than the geosciences, and only 17.9 % (14) majored in the geosciences. The REU scholars spanned 29 different STEM majors (Table 6.1). Among the 78 students, 42.3 % (33) of them identified themselves as African-American (non-Hispanic), 20.5 % (16) as Hispanic, 20.5 % (16) as Asian/Pacific Islander, 15.4 %

Table 6.1 REU scholars by STEM majors

Major (N = 78)	*Number of students (%)*
Architectural Technology	1 (1.3 %)
Biology	1 (1.3 %)
Biology Engineering	1 (1.3 %)
Biomedical Informatics	1 (1.3 %)
Civil Engineering	7 (9.0 %)
Computer Engineering	1 (1.3 %)
Computer Engineering Technology	2 (2.6 %)
Computer Information Systems	1 (1.3 %)
Computer Science	6 (7.7%)
Computer Systems Technology	2 (2.6 %)
Earth and Atmospheric Sciences	5 (6.4 %)
Electrical Engineering	8 (10.3 %)
Engineering Science	2 (2.6 %)
Environmental Control Technology	1 (1.3 %)
Environmental Engineering	8 (10.3 %)
Forensic Science	1 (1.3 %)
General Science	1 (1.3 %)
Information Systems Management	1 (1.3 %)
Liberal Arts and Sciences	2 (2.6 %)
Mathematical Science	5 (6.4 %)
Mathematics (Applied)	5 (6.4 %)
Mathematics Education	1 (1.3 %)
Mechanical Engineering	6 (7.7 %)
Mechanical Engineering Technology	2 (2.6 %)
Medical Laboratory Science	1 (1.3 %)
Meteorology	1 (1.3 %)
Neuroscience	1 (1.3 %)
Physics	3 (3.8 %)
Telecommunications Engineering Technology	1 (1.3 %)

(12) as Caucasian, and 1.3 % (1) as other. The program had 64.1 % (50) males and 35.9 % (28) females. Of the total cohort, 83.3 % (63) of the participants were considered underrepresented minorities in the STEM disciplines (defined as Blacks or African-Americans, Hispanics or Latinos, American Indians or Alaskan Natives, Native Hawaiians or other Pacific Islanders, or females).

The students participated in a range of interdisciplinary research projects in satellite- and ground-based remote sensing. These interdisciplinary research projects focused on the study of the earth's atmosphere, hydrosphere, cryosphere, biosphere, and lithosphere. The projects included the study of hurricanes, atmospheric water vapor distribution, soil moisture, vegetation, sea ice, air quality, coastal waters, and climate change. REU scholars from among the disciplines in Table 6.1 successfully completed and presented their geoscience research projects at numerous national, regional, and local conferences across the country. Many of them have won awards at these and other geoscience and STEM conferences. Sample research project titles by student majors are shown in Table 6.2.

Table 6.2 Sample research project titles by student majors

Student majors	*Research project titles*
Architectural Technology	• Exploring DMSP (Defense Meteorological Satellite Program) SSM/T2: Measurements to understand atmospheric water vapor distribution
Biomedical Informatics	• Spatial variability of ambient ozone concentrations during three heat waves in the northeast megaregion of the USA
Civil Engineering	• Developing an algorithm to investigate cloud lifetime using GOES satellite thermal channel information
Computer Engineering	• Combining Spatial Kriging with satellite estimates to obtain a regional estimation of PM2.5
Computer Engineering Technology	• Observing aerosol mass densities during the trans-Atlantic transport of Saharan dust and biomass burning aerosols
Computer Science	• Flood prediction using multidimensional analysis of precipitation and inundation in the Mekong river delta
Earth and Atmospheric Science	• Creating water body maps for the Pacaya Samiria, the everglades, and the US gulf coast using NASA UAVSAR imaging radar data
Electrical Engineering	• Use of reconnaissance aircraft data in estimating hurricane intensity
Environmental Engineering	• Modeling optical properties of aerosols using microphysical retrievals from air quality models
Information Systems Management	• Band 6 restoration for snow mask: Yellowstone case study
Liberal Arts and Sciences	• Detection of land cover change and drought trend using brightness temperature and microwave emission
Mathematics (Applied)	• Remote sensing of ice in the Caspian sea via MATLAB programming
Mechanical Engineering	• Preliminary analysis: electricity consumption changes in California
Mechanical Engineering Technology	• Use of satellite images for surface conditions monitoring in the upper Mississippi watershed during the flood event of 2008
Physics	• Connecting air pollution parameters to optically measured parameters to assess air quality monitoring capabilities

Not only were the REU scholars' projects interdisciplinary in nature, but their faculty mentors themselves were also from a variety of disciplines and interdisciplinary research fields. Faculty members participating in the REU program were renowned scientists from CREST located at the City College of New York. CREST is a NOAA research facility that specializes in satellite- and ground-based remote-sensing research. Faculty mentors were also from CREST affiliates formed with City Tech's Remote Sensing and Earth System Sciences (ReSESS) Center and the Bronx Community College's Geospatial Center. Faculty mentors were also from NOAA line offices. Research foci ranged from developing satellite multi-sensor rainfall and snowfall retrieval algorithms and merging model estimates with ground truth measurements to improve quantitative precipitation estimation (QPE) of the construction of global aerosol, cloud, and trace-gas climatologies derived from satellite measurements. A list of some research expertise of faculty mentors by department is found in Table 6.3.

The results from completing the one-year REU program have been generally positive. Of the 78 REU scholars who have participated in the program, 18.8 % (15) of them are in graduate school in the STEM disciplines, 16.3 % (13) of them have graduated and are now employed in the STEM workforce, and 65 % (51) of them are continuing with their STEM majors. Moreover, four of the REU scholars have won first-place recognition for their research at national and regional conferences, another four have won second-place recognition at regional and local conferences, and three other REU scholars are co-authors for two peer-reviewed publications and one book chapter. The REU program claims a 100% STEM retention rate for its REU scholars.

The REU scholars evaluated their experience by completing selected questions from the Undergraduate Research Student Self-Assessment survey.[6] The focus of the survey was that a standard set of potential learning gains from the one-year research experience was collected for evaluation from each student respondent. Of the 78 students, 37 responded to the survey. The results in Table 6.4 showed positive student-reported gains in the following four areas:

1. *Thinking and working like a scientist*
   REU scholars reported "good" to "great" gains in understanding how connected or interdisciplinary the various scientific disciplines really are to each other. They gained understanding of how science research is conducted; thus, their analytical skills in identifying pat-

Table 6.3 Faculty research expertise by STEM departments

STEM department	*Research expertise*
Civil Engineering	• Water resources and land hydrology: development of advanced techniques for monitoring of hydrometeorology from passive and active microwave satellite observations
Construction Management and Civil Engineering	• Civil engineering and water resources: using satellite information in climate studies, vegetation structure profile, soil moisture estimation, snow cover prediction, precipitation, and estimation of soil freeze/thaw state
Earth and Atmospheric Sciences	• Meteorology: satellite remote sensing and clouds in the context of climate and climate change
Electrical Engineering	• Improvement of methods for using current and future satellite measurements in air quality forecasting (MODIS, MISR, CALIPSO, APS, VIIRS, GOES-R, etc.) • Tropospheric remote sensing and air quality (TRAQ): satellite algorithm development and validation, ground-based remote-sensing network, ground-based in-situ measurements, sampling and sample analysis and speciation, modeling and validation, and health impacts • Remote sensing of coastal waters: evolution of measurements approaches for coastal water parameters, development of suite of field measurement capabilities for algorithm testing and satellite validation in coastal waters, and improvement/development of algorithm for remote sensing of coastal waters
Electrical Engineering Technology	• Optics and remote sensing of the atmosphere as well as model development and model validation using land- and space-based remote-sensing systems. Specializes in modern optical metrology systems used in noncontact measurements of space instruments
Mechanical Engineering	• Energy, sustainability, climate change, climate modeling, and remote sensing: recognized in the field of urban climatology, remote sensing, and renewable energy
Physics	• Tropical meteorology: specializes in the use of satellites to study hurricanes, climate and climate change impacts, urban climate and micro-meteorology, and remote-sensing applications to air pollution and hydrometeorology

terns and interpretation skills of the results generated were increased. Moreover, these students indicated higher gains in expanding and grounding their knowledge of the geosciences from the REU experience.

2. *Personal and professional gains related to research work*
   "Good" to "great" gains were reported in the REU scholars' confidence in their ability to do well in future science courses and

Table 6.4 Means and standard deviations of responses regarding benefits gained from the REU research experience

Benefits gained from the REU research experience: 1 = no gain, 2 = a little gain, 3 = good gain, 4 = great gain	*Mean (SD); N = 37*
Gains in thinking and working like a scientist	
Understanding how science research is done	3.58 (0.55)
Understanding how to collect scientific data	3.38 (0.79)
Problem-solving in general	3.35 (0.79)
Analyzing data for patterns	3.47 (0.61)
Interpreting results from analyzing scientific data	3.31 (0.75)
Identifying limitations in research methods and designs	3.16 (0.93)
Understanding the connections among scientific disciplines	3.39 (0.65)
Extending my knowledge	3.69 (0.58)
Solidifying my knowledge	3.50 (0.74)
Personal gains related to research work	
Confidence in my ability to do research	3.41 (0.83)
Confidence in my ability to contribute to science	3.36 (0.80)
Comfort in working collaboratively with others	3.42 (0.73)
Confidence in my ability to do well in future science courses	3.58 (0.65)
Gains in becoming a scientist	
Ability to work independently	3.36 (0.64)
Understanding what everyday research work is like	3.39 (0.73)
Gains in skills	
Writing scientific reports or papers	3.08 (0.87)
Making oral presentations	3.44 (0.69)
Defending an argument when asked questions	3.24 (0.78)
Preparing a poster	3.58 (0.55)
Working with computer software	3.53 (0.61)
Understanding journal articles	2.92 (0.80)

contribute to science, to conduct research, and to work in a collaborative setting.

3. *Becoming a scientist*
   REU scholars showed "good" to "great" gains in their ability to work independently and in their understanding of what doing and conducting research is like as a scientist.
4. *Skills*
   Higher gains were reported in the REU scholars' ability to present their research orally, prepare a poster presentation, and use MATLAB in analyzing their data. They also indicated "good" gains in their ability to write scientific papers and understand scientific journal articles.

In addition, questions regarding benefits gained from the various REU program components were solicited from the students (Table 6.5). With respect to the mini-courses, the REU scholars reported higher learning gains for MATLAB followed by statistics. Reasonably, the MATLAB and statistical abilities gained by the REU scholars are particularly portable and valuable for those majoring in a STEM discipline. For the mentoring component, the survey showed that REU scholars valued their graduate or post-doctoral research scientist mentors over their faculty scientist mentors. Because most of the research time was spent under the direction and guidance of their graduate or post-doctoral research scientist mentors, the REU scholars indicated greater learning gains from them. However, the REU scholars found "little" to "good" gain in mentoring their assigned high-school students. Overall, there were "good" gains from the community of REU scholars.

The REU scholars found the geoscience exposure trips rewarding. Through their interactions with the scientists, students discovered how interdisciplinary the scientists were in their expertise and in the positions they occupied. This awareness was particularly noted when the students

Table 6.5 Means and standard deviations of responses regarding the REU program components

Benefits gained from REU program components: 1 = no gain, 2 = a little gain, 3 = good gain, 4 = great gain	*Mean (SD); N = 37*
Mini-courses	
MATLAB mini-course	3.24 (0.99)
Remote-sensing mini-course	2.91 (0.89)
GIS mini-course	2.88 (0.91)
Basic statistics mini-course	2.97 (0.91)
Remote-sensing orientation seminars	3.00 (0.91)
Mentoring	
Faculty scientist mentoring	3.08 (0.87)
Graduate student/post-doctoral research scientist mentoring	3.26 (0.99)
High-school mentee	2.70 (0.93)
Community of REU scholars	3.14 (0.93)
Field experiences	
American Museum of Natural History	2.97 (0.87)
Brookhaven National Laboratory	3.35 (0.71)
National Weather Service	3.41 (0.71)
Cary Institute	3.15 (0.99)
NOAA Center for Weather and Climate Prediction	3.67 (0.59)

visited the NOAA Center for Weather and Climate Prediction and the National Weather Service. The REU scholars also highly valued their participation at national, regional, and local conferences and events.

To capture students' perspectives (expectations, experience, knowledge, ability, exposure to research, future goals, etc.) of the REU program, a series of formative and summative assessment surveys were also conducted. The survey results revealed the following:

- The mini-courses in MATLAB, GIS, and remote sensing were extremely effective in providing the STEM students with the necessary foundation for interdisciplinary satellite- and ground-based remote-sensing research.
- The mini-course in statistics was useful and applicable not only for their geoscience research, but also for their own STEM majors.
- Due to their participation in the REU program, most of the students plan to pursue STEM graduate degrees.
- On average, REU scholars each made about six presentations of their interdisciplinary REU geoscience research at national, regional, or local conferences; by so doing, the survey results indicate that their oral and poster presentation skills have tremendously improved.
- Due to their participation in the REU program, REU scholars have gained a greater motivation for interdisciplinary learning.
- Their participation in the REU program has made them independent, interdisciplinary thinkers while simultaneously enabling them to function well within a community of learners where teamwork is essential.
- Due to their participation in the REU program, the likelihood of the students pursuing both Master's and PhD degrees in the geosciences (satellite- and ground-based remote sensing) significantly increased.
- REU scholars now feel that they understand better how to think critically like geoscientists do.
- After the one-year REU experience, REU scholars felt prepared for more demanding geoscience research endeavors, and their analytical and data management skills have improved.
- Many of the REU scholars enjoyed their interdisciplinary, geoscience mentoring experience—both by being mentored by graduate students and by providing guidance to their high-school mentees.

Reflections on the REU Experience

A number of REU scholars reflected on their experiences within the course. For example, one Mathematics major stated, “I gained valuable programming skills which made my mathematical modeling classes easier. I gained public speaking skills which were essential in class presentations. Lastly, I was able to experience a working application of the concepts I studied.” Likewise, a Biomedical Informatics major remarked that the REU program “gave me more computational skills and research tools, and [it has] allowed me to use those skills for my biomedical informatics program.” In addition, a Mechanical Engineering major credited the course for its improving reasoning skills: “The REU program taught me to think critically and beyond information provided to you. This is because research requires one to think beyond what has already been done. The professor I worked with always pushed me to think this way and to maintain a positive outlook despite the challenges. This made my academic class work seem like a breeze!” Another student remarked on the way the course helped students think in interdisciplinary ways that will help them in their future careers: “As a Computer Science major, I was primarily in the software development aspect of the REU. I was able to hone my skills for the industry while working with other researchers and scientists to develop tools to make research easier. This broadened my understanding of other areas in the industry knowing that my major could be involved with different majors and backgrounds and creating collaboration.” Another Biomedical Informatics major also hailed the way the course promoted interdisciplinary thinking: “I really appreciated this opportunity to embark on a journey to broaden my understanding of the sciences in general by working in close cooperation with a professional in the field on a discipline in which I had no previous knowledge. I feel that I have grown both as an individual and as a professional.”

In addition to these reflections, other programmatic assessments reveal that many of the underrepresented minority students in the program would not have continued down the pathway toward advanced degrees were they not trained and provided with the interdisciplinary geoscience experiences of the program. The interdisciplinary training they received boosted their confidence, increased their critical thinking skills, and improved their understanding of the environmental complexities for which they seek solutions. Members of the full cohort of REU scholars have now joined the ranks of a new cadre and corps of interdisciplinary learners and practitioners who are equipped and trained with the necessary skills sets, confidence, and ability to tackle the many interdisciplinary challenges that exist and that will emerge throughout this century. They have been taught how to approach, investigate, and interrogate with the interdisciplinary tools and mindset that the REU program gave to and developed in them.

Conclusion

As the need for interdisciplinary learning becomes more of a national imperative, this REU program demonstrates that a comprehensive geoscience research experience given to STEM majors at the appropriate academic juncture can be a useful and efficient method to bring about critical interdisciplinary outcomes. Since twenty-first century problems have become less discipline-specific and more interwoven across disciplinary boundaries, careful and intentional knitting of different disciplinary strands can produce the integrative tools necessary to confront complex problems. Knitting various strands of STEM disciplines, for example, can produce interdisciplinary ingenuity and innovation that not only excites STEM students, but also equips them with the skills and the confidence needed to analyze, understand, and seek solutions to problems of many scales and of many resolutions. The tasks and the problems of the twenty-first century are challenging and daunting, and any amelioration of them must be sought via the mechanisms and methodologies that are inherent and sui generis to interdisciplinary scholarship; this type of scholarship needs to be embraced by institutions of learning and made available to students now, not later. National and global security and advancement hinge on this pivotal scholastic paradigm.

Finding solutions to the difficult, multi-pronged problems that face humankind at all levels and in all sectors will require bold new pedagogic initiatives that are needful, practical, and make simple common sense. Popper is correct: if problems have no disciplinary borders, then their solutions must mimic their disciplinary un-restrictedness. To this end, the following six recommendations are offered. First, educators should acknowledge that complex problems (and their solutions) are often not hemmed in by disciplinary boundaries. Second, understand the individual components (disciplines) involved in the problem before attempting to delineate the relationships (interdisciplinary nature) between them. Third, promote interdisciplinary learning and its many advantages. Fourth, introduce, expose, and engage students in interdisciplinary learning early and often. Fifth, set clear, achievable, and measurable interdisciplinary student learning goals. Finally, expand the experiment of this study to non-STEM disciplines.

Consequently, for formidable societal challenges to be met, and for learning to be truly optimized, a philosophical paradigm shift toward interdisciplinary pedagogy is needed among the educational cauldrons in which knowledge brews and from which knowledge is dispensed. Institutions of learning will need to embrace this paradigm shift if they are to remain relevant and contributory to global advancement. Many institutions will have to revive, reconfigure, and reimagine extant programs and courses and simultaneously introduce new ones so as to attract and educate a new and growing company of revolutionary, interdisciplinary thinkers and scholars. Old frameworks and dull, unimaginative, pedantic schemes of packaging and delivering the product of knowledge will soon be abandoned and discarded, for they are inadequate and ill-designed to meet the needs of a rapidly advancing and interdependent local, regional, national, and global populace. Interdisciplinary courses, interdisciplinary research projects, and interdisciplinary professional development training for faculty will feature prominently in this new and necessary paradigm. Fresh, interdisciplinary perspectives promise to invigorate and enliven both faculty and students and thereby transform academic institutions into continuous, sustainable beehives of interdisciplinary activities that are replete with practical challenges that will both require and produce a hub of innovation, discovery, and intellectual stimuli. The time has now come for a widespread, far-reaching, interdisciplinary renaissance to open and to expand a critical mode of acquiring and dispensing knowledge. Therefore, let the potential of mutual symbioses of disciplines be explored; let interdisciplinary learning be a formidable tool to subdue and overcome twenty-first century challenges, and let the new renaissance begin!

Notes

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