PROJECT SUMMARY

Overview:

This proposal to IUSE:EHR Engaged Student Learning, Exploration and Design would fund a project to significantly expand resources for undergraduate geoscience student learning of geodetic field methods, research the implementation of resources by faculty in field experiences, and develop a framework to scale to multiple technologies and reach multiple universities. It was conceived in response to years of community requests for more geodesy field education support and shaped by community recommendations from a workshop and survey. This project will develop, test, and disseminate two learning modules featuring geodetic field methods relevant for a wide array of geoscience applications. The project will include robust measure of student learning, dissemination of developed resources to faculty members in short courses, and research of faculty implementation. This exploratory project lays the groundwork for broader integration of geodetic methods into geoscience field courses in the future.

This collaboration brings together expertise in geodetic field methods, field instruction, curriculum design, and science education research. The Science Education Resource Center (SERC) will provide assessment consulting, research support, project evaluation, and website hosting. National Association of Geoscience Teachers (NAGT) will support dissemination. The module development process closely follows the previous projects for development, assessment, and evaluation. The work leverages five years of experience on the part of UNAVCO and Indiana University on collaborative curriculum development and teaching TLS at an undergraduate field camp. Thus, half of one module has already been developed and field-tested, starting the project with a faculty short course and collection of research data on faculty adoption of materials.

Learning modules will provide instructional faculty resources to teach geodetic technologies in ways that help students develop critical thinking and other skills necessary to succeed in applied and academic sciences. A second emphasis is on training and dissemination including short courses for faculty members with both technical and pedagogical aspects, providing a pathway for improved teaching methods in the field and classroom. Finally, research is needed on the effective adoption of field education teaching materials created by someone else. Adoption and adaptation will be studied at five universities.

Intellectual Merit :

Fieldwork is an integral part of Earth sciences and there is a longstanding tradition of teaching field methods as part of the undergraduate curriculum. There is growing demand for integration of technology into geoscience field education settings, and increased interest in the use of geodesy in field education. This project provides a pathway for faculty to effectively integrate geodetic technologies in field experiences. Data collected during the implementation and testing of learning modules will contribute to the body of educational research by analyzing the process of adoption of curricular materials by instructors in diverse field settings.
This research will aid the efficiency of future curriculum development through better understanding of instructor needs. As new technology changes the ways in which we scientifically examine Earth, and as workforce development demands evolve, there is growing interest and need in introducing these technologies into field education curricula.

Broader Impacts :

The geodesy-focused topics are of great need in undergraduate instruction. Geodetic field technologies can be applied to a broad range of societally critical geoscience topics as well as non-scientific applications. The materials will be a resource to geoscience faculty and potentially faculty from other disciplines that incorporate geodetic technologies and instrumentation in their work. In addition, during the process of module development two faculty authors and two supporting graduate students will received considerable professional development on high quality curriculum development and ~50 geoscience instructors will receive training on technical and pedagogical components of geodetic field teaching. Research findings will be disseminated to other geoscience disciplines engaged in field education.

1. INTRODUCTION

This project aims to improve student learning in geoscience field education through development of teaching modules that combine geoscience content and geodetic technologies. These modules will be disseminated through faculty short courses and online. Geodesy is the study of the size, shape, and mass of the Earth and their changes with time – recent developments have revolutionized our understanding of Earth processes and produced discoveries of major societal impact. Geodetic field techniques are particularly valuable for hazard assessment, stratigraphic analyses, and understanding plate tectonic and geomorphic processes [Amos et al., 2007; Baldo et al., 2009; Kaneko, 2010; Reilinger et al., 2010; Ching et al., 2011; Munnecke et al., 2012; Vernant et al., 2013; Barreca et al., 2014; Bebeck at al., 2015], but increasingly geodetic technologies are also applied across a range of geoscience and engineering disciplines [e.g., Schaffrin & Wieser, 2009; Haddad, 2011; Anthes et al., 2014; Dausz et al., 2014; Wang, 2014]. A national priority is ensuring that the next generation of geoscientists are fully prepared to enter the workforce [NRC, 2010a,b; Holdren et al., 2013], and exposure to geodesy and geodetic technologies is a key part of that preparation. Nationally, geoscience-related occupations are in demand with an estimated 16% increase in new jobs by 2020 [Bureau of Labor Statistics, 2015; Wilson, 2014]. The existing geoscience workforce is aging while the energy and environmental sectors in the U.S. are expanding [Gonzales and Keane, 2010; NRC, 2011b]. In addition to content knowledge and technical capability, students need a variety of skills ranging from critical thinking to communication to be successful in geoscience careers [Niemitz and Potter, 1991; Carlson, 1999; Orion & Kali, 2005; Grant et al., 2015]. We propose to explore the development of a scalable infrastructure to support student learning of field geodesy techniques and to research the implementation and adaptation of such materials by field instructors. This project is proposed as an *Engaged Student Learning* track *Exploration and Design* tier. It will provide a framework for future integration of more geodetic methods and technologies into a broader range of geoscience field courses and in turn, classrooms.

Through collaboration between UNAVCO, Idaho State University, and Indiana University, this project will develop flexible, scalable field education learning materials that will expose students to a variety of instrumentation, data and techniques, and increase their understanding of geodetic applications. The project leverages considerable experience in curriculum development, assessment, and dissemination from the SERC-led (Science Education Resource Center) NSF STEP Center project – InTeGrate (http://serc.carleton.edu/integrate) and NSF TUES project, GETSI (GEodesy Tools for Societal Issues; http://serc.carleton.edu/getsi). Both InTeGrate and GETSI are developing undergraduate earth science learning modules that are firmly rooted in societal importance. This proposed project will also provide professional development opportunities and resources for faculty from the UNAVCO and broader geoscience community so they have the efficacy to incorporate cutting edge geodetic techniques into their curriculum. Research on how faculty implement the module materials into their field education experiences will contribute to an area of geoscience education lacking in robust investigation. The UNAVCO consortium includes members from 207 educational or nonprofit institutions from around the world including 108 U.S. universities. UNAVCO operates the National Science Foundation's Earth Science Geodetic Facility, known as the Geodesy Advancing Geosciences and EarthScope (GAGE) Facility. The GAGE Facility provides support to the NSF investigator community for geodesy, related research, education, and workforce training with broad societal benefits.

Working in the field provides a unique opportunity for students to explore phenomena directly [Stillings, 2012]. Field studies allow students to make their own informed decisions based on experiential learning [Latour, 1987; Bluth & Huntoon, 2001] and field experiences have long been a part of undergraduate geology education [AGI, 2001; Drummond & Markin, 2008]. As geoscience evolves, so must field work and field-based education. UNAVCO supports community requests for geodetic field research, primarily with static global positioning system (GPS) and terrestrial laser scanning (TLS) technologies. Other related field geodetic technologies common to modern research and used in various applications include Real Time Kinematic GPS (RTK GPS), photogrammetric techniques such as Structure from Motion (SfM), airborne and mobile lidar (light detection and ranging), and space-borne remote sensing with interferometric synthetic aperture radar (InSAR). Many of these emerging technologies are not typically found in textbooks and instructional lab manuals and therefore incorporating them into university instruction is challenging at best. This project will develop and test the resources necessary for students to gain experience with, and exposure to, a variety of geodetic technologies. Faculty will receive instructional materials and professional development training to support the integration of content into summer and in-semester field experiences using pedagogically sound instructional methods.

Keeping geoscience instruction current through the incorporation of cutting-edge geodetic technologies in field education moves the student experience beyond the “rock hammers and colored pencils” that have traditionally been central to field experiences. This continued advancement of science instruction is a high priority for the NSF and agencies across the federal landscape. The integration of hands-on STEM learning aligns with NSF Strategic Objectives: (G1/O2) *Integrate education and research to support development of a diverse STEM workforce with cutting-edge capabilities* and (G2/O2) *Build the capacity of the Nation to address societal challenges using a suite of formal, informal, and broadly available STEM educational mechanisms* [NSF, 2014] and directly relates to supporting the NSF HRD mission to growing the innovative and competitive U.S. STEM workforce [NSF, 2015]. As an NSF facility, UNAVCO is charged with educating and preparing the next generation STEM workforce to conduct transformative research in earth sciences using geodesy and geodetic techniques [NSF, 2014; UNAVCO, 2011].

2. PROGRAM GOALS AND OBJECTIVES

The primary program goal is to improve students’ Earth science understanding and workforce-ready capabilities through field education experiences that incorporate geodetic technologies and applications. Resources (inputs) for this project include NSF funding, the UNAVCO GAGE Facility, faculty collaborators, SERC, NAGT (National Association of Geoscience Teachers), and the geodesy community. The three goals are student-focused either directly or toward improving instruction through faculty development.

Goal 1. Build student understanding of geodetic instrumentation, techniques, and applications
- Objective 1.1: Increase student understanding of geodetic instrumentation, methods, and applications, specifically Terrestrial Laser Scanning (TLS), Structure from Motion (SfM), and Static and Real-time Kinematic (RTK) Global Positioning Systems (GPS)
- Objective 1.2: Increase student ability to collect, analyze, manipulate and interpret geodetic field data
- Objective 1.3: Increase students’ knowledge of the array of scientific challenges and problems that can be studied using geodetic tools

Goal 2. Increase faculty efficacy in teaching geodetic techniques in geology field courses
- Objective 2.1: Develop robust learning modules for field or classroom use that are flexible enough for instructors to integrate into field camps and classes
- Objective 2.2: Increase faculty knowledge of best practices for instruction in field courses

Goal 3. Obtain baseline data from faculty to better understand successes and challenges of implementing pre-developed curricular materials in field education experience
- Objective 3.1: Document faculty experience in field instruction, motivation for incorporating geodetic technologies, and working knowledge of best pedagogical practices

Project activities will result in (outputs): two modules (up to eight units each) for incorporating geodetic technologies in field education, multi-day professional development workshops for geoscience faculty, one-day short courses for faculty training, baseline data to begin to understand how faculty adopt curricular materials into their field instruction, and student data contributed to the GLE (Geosciences Literacy Exam) national database. The student and faculty outcomes are articulated in the project objectives.

3. PROJECT DESCRIPTION

We propose to (1) develop, test, and disseminate two modules (*Analyzing High Resolution Topography* and *High Precision Positioning*) that will incorporate four geodetic data collection techniques. These modules will increase student knowledge of geodesy instrumentation, methods, and applications. We will also (2) facilitate professional development of faculty on the teaching materials and implementation of the modules. As we develop and disseminate these materials we will (3) research the process of adaption and adoption of field geoscience curricular materials by instructors in different field settings, contributing to the very limited body of knowledge on student assessment instruments for geoscience field education.

3.1 Motivation. Geodesy is the study of the size, shape, and mass of the Earth and their changes with time. Technologies that enable us to observe and quantify these changes have expanded and advanced substantially over the past decade, offering improved accuracy, higher spatial resolution and observation density, and decreased cost and size. GPS (and increasingly GNSS [global navigation satellite system]) observations from permanent and campaign sites, are now complemented by space, airborne, and terrestrial observations using technologies such as radar, lidar, and photogrammetry. Collectively, this suite of geodetic technologies have expanded how we image changes in the Earth [Ashkenazi, 2006; Plag & Pearlman, 2009]. Field geodetic technologies are being applied to an ever-expanding suite of disciplines to study problems of societal concern (e.g., hazards; energy reserves; paleoclimate reconstruction; biomass; surface processes) [e.g. Johnson et al., 2014; Holopainen et al., 2011; NRC, 2010a; Wdowinski & Eriksson, 2009]. Beyond academia, geodetic technologies such as GPS and lidar have become fundamental to a wide range of commercial applications. The innovative UNAVCO community has lead the use of geodetic technologies in the geosciences, and is well positioned to take a leadership role in integrating these technologies more closely into geoscience field education. Students will gain opportunities to operate geodetic instrumentation and explore the data from these technologies, thus developing a skill set that is transferrable to a variety of geoscience and interdisciplinary areas, and ultimately better prepares students to enter the workforce.

Fieldwork is an integral part of the geosciences and there is a longstanding tradition of teaching field methods as part of the geoscience undergraduate curriculum [Macdonald et al., 2005; Douglas et alk, 2009; Kelso & Brown, 2009; Petcovic, et al., 2009; Riggs et al, 2009a,b; Vance et al., 2009; LaDue & Pacheco, 2013]. Despite its perceived importance [Petcovic, et al., 2014], relatively little research has gone into assessing ways to maximize student learning of field methods [Elkins and Elkins, 2007; Maskall and Stokes, 2008; Stokes & Boyle, 2009]. As new technologies are integrated into Earth science research and as workforce development demands evolve, there is growing interest in introducing these technologies into field education curricula [Phillips et al., 2012a; Douglas et al., 2014]. Students - the next generation of scientists - must be both aware of the broad range of technologies available to study these multi-disciplinary problems as well as have the skill set to determine when to utilize each technology/instrument [e.g., Bangen et al., 2014]. This project will provide the basis of infrastructure for geoscience faculty to incorporate geodetic technologies into field experiences and students will gain essential geoscience workforce skills and knowledge.

Currently, there are few resources for faculty to draw on to incorporate geodetic field technologies into the undergraduate curriculum. Geodesy is a sub-discipline of geosciences and typically, faculty who teach geoscience field camps do not have expertise in geodetic technologies or methods. Through community workshops and a survey, the geoscience community has articulated the need for instructional resources focused on geodetic technologies, including teaching materials to support use of geodetic instrumentation and data both in the classroom and field camps [Phillips et al., 2012a,b; Douglas et al., 2014]. The primary recommendations were: 1) Increase the visibility of UNAVCO field education services; 2) Provide technical and pedagogical professional development for static GPS, RTK GPS, TLS, and SfM; and 3) Make teaching resources available online. Faculty see the imperative of providing students hands-on experiences as geodetic technologies are increasingly used for academic and industrial applications. Correspondingly, accessibility to these tools for university geoscience departments is improving, due in part to decreases in cost, shared community resources such as those provided by UNAVCO, and simplified workflows [Stempfhuber & Buchholz, 2011].

The largest ongoing undergraduate geoscience curriculum effort, InTeGrate (funded by NSF), is primarily aimed at introductory courses [Manduca et al., 2013]. Our proposed project will help fill a gap by providing more technical, majors-level learning resources. Several members of the UNAVCO community have initiated preliminary instruction in field geodesy and various technical “manuals” exist for researchers and graduate students, but curricular resources for undergraduate instructors are essentially non-existent, as demonstrated by searches of SERC and Digital Library of Earth Science Education (DLESE). UNAVCO community members (see letters of commitment) have committed to supporting this project by providing prototype teaching resources, technical advice, short course co-instruction, and/or materials testing and feedback so that the project can build on what limited resources do exist.

Various parts of the produced materials will also address key science literacy principles by increasing student knowledge on six of the nine *Earth Science Big Ideas* [ESLI, 2009] - 1: Earth scientists use repeatable observations and testable ideas to understand and explain our planet; 3: Earth is a complex system of interacting rock, water, air, and life; 4: Earth is continuously changing; 7: Humans depend on Earth for resources; 8: Natural hazards pose risks to humans; 9: Humans significantly alter the Earth.

3.2 Module content. Two modules will be developed, each focused on two geodetic methods and comprised of seven or eight individual units. The modules will have comprehensive resources to support both student learning and instructor adaption and adoption. The first units will be method fundamentals and background needed to complete any of the subsequent units. The remaining units will be designed for flexibility so that instructors can select the geodetic method/s and geoscience research question/s that best suit their geographic location and course topic. The summative assessment will also be flexibly structured so that a range of potential research questions could be addressed. It is expected that most instructors would choose to do 3 to 4 units in any given course – thus including the introduction, 1-2 topical units, and the summative assessment. This is equivalent to 4 to 5 days of a full-day field course or approximately two weeks in an academic-year course. For instructors interested in utilizing both geodetic methods from a given module, resources will provide support for developing student critical thinking skills by evaluating the pros and cons of each method, given a specific research task and field site [e.g. Bangen et al., 2014]. For instructors unable to incorporate field data collection into their course, the modules will also supply prepared data sets from which the same scientific analyses can be performed.

Two fundamental geodetic observations are: 1) detailed measurement of the three dimensional shape of the Earth's surface and changes to that shape with time, and 2) precise positioning of points on the Earth's surface and tracking changes in those positions with time. These two fundamental classes of observations will guide the structure of the modules we propose to develop. The modules are further informed by recommendations from a community workshop and survey [Douglas et al., 2014], and the existing strengths of UNAVCO technical capacity:

- *Module 1: Analyzing High Resolution Topography* - TLS and SfM
- *Module 2: High Precision Positioning* - static GPS and RTK GPS

Module 1: Analyzing High Resolution Topography

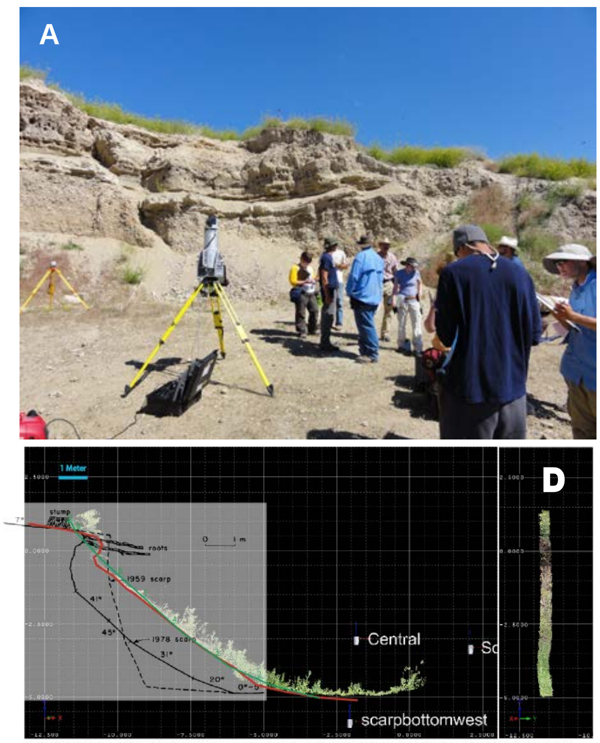
Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM) are geodetic observation methods that generate high resolution topographic data. TLS does so with dense laser measurements of the landscape from a tripod-mounted lidar instrument. SfM is a photogrammetric technique that uses overlapping images to construct a 3D model of the scene. SfM can be collected from a hand-held camera or an airborne platform such as an aircraft, tethered balloon, kite, or UAS (unmanned aerial system) [Fonstad et al., 2013]. The resultant data product from both methods is a dense "point-cloud" that represents the three-dimensional shape of the landscape. There are advantages and disadvantages to both techniques. TLS field methods are complex and can be time intensive, and laser scanners are expensive (10s to 100s of thousands of dollars) but are precise and can collect data at great range (> 1 km). SfM generally requires less field time and hardware relies on consumer-grade cameras, making it much more affordable. SfM is challenged by dense vegetation (whereas TLS can "see" through vegetation), and data processing is computationally intensive, often requiring hour to days to produce products.

In summer 2015, UNAVCO and Indiana University developed five units of learning materials on TLS by compiling prototype materials from previous years of exploratory TLS field education support (Figure 1), [Charlevoix, et al., 2015; UNAVCO, 2015b]. The materials include *Unit 1: Introduction to TLS*, *Unit 2: Survey of a stratigraphic section*, *Unit 3: Survey of a fault scarp*, *Unit 4: Survey of geomorphic change*, and *Unit 7: Summative assessment*. They were tested in two field camps during summer 2015 and showed very promising initial student data results with all students accomplishing the two module goals and four guiding principles (more details in Section 3.3) to at least a satisfactory extent. The module will be expanded to include ~2 more units on SfM survey execution and data processing. Completion of the SfM component of the module, a final external review (by SERC), and online publication will be the first activity of this project, completed for use in a late-summer 2016 faculty professional development session at the Indiana University Geologic Field Station (IUGFS).

Coincident with finalizing the existing units, the project team will develop the agenda and training materials necessary for conducting a multiple-day short course at IUGFS in August. The short course will provide training on TLS instrumentation, best pedagogical practices in field education, and design of classroom or field experiences to maximize student learning while using geodetic technologies. After faculty complete the professional development and training, they are eligible to submit a request for support to UNAVCO to incorporate TLS into their field education courses (see Section 3.5 below for request process). The primary short course instructors will be Dr. Douglas and C. Crosby with support from Drs. N. Niemi and M. Clark (Univ. Michigan) and B. Wang (Univ. Houston) (see letters).

Module 2: High Precision Positioning

Using signals from four or more GPS/GNSS satellites, high precision GPS receivers have the ability to measure locations at decimeter to millimeter scales, depending on the method, equipment, and data processing. This module will feature static or "campaign" GPS and real time kinematic (RTK) GPS. The former involves periodically revisiting and occupying (for 1 or more days) established benchmarks to determine change. RTK involves a roving unit in communication with a local GPS base station to measure locations over a larger area. Static GPS is more accurate (sub-cm) but much more spatially sparse, as a limited number of observations are possible, and requires more intensive data processing. RTK allows rapid mapping of vastly more points with fewer data processing challenges, but the accuracy is lower (several cm).



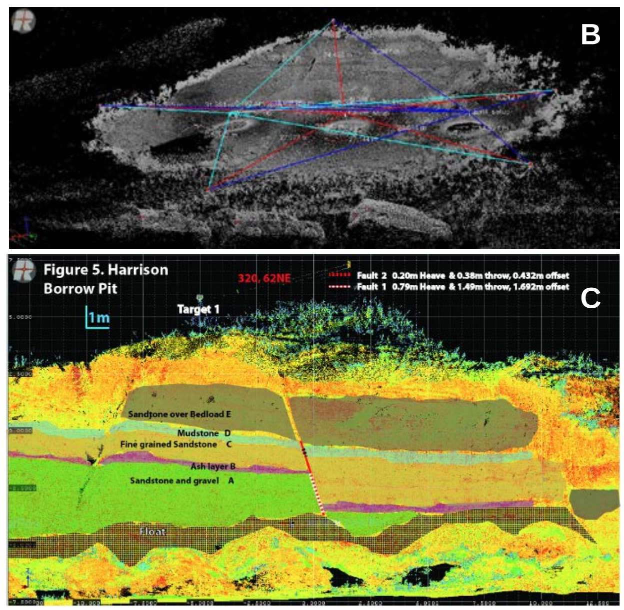


Figure 1. A) Indiana University Field Camp students set up a TLS scan of a borrow pit containing an active fault. B) An image of the final TLS point cloud with three scanning positions and links to all reference targets. C) Example of a student's analysis of the fault history (work of: Kort Butler, G429g, 2013). D) Student work showing their analysis of the Cabin Creek segment of the 1959 Hebgen Lake earthquake fault (work of Doran Howell, G429g, 2013). This analysis was accompanied by simple numerical modeling of fault scarp roll back.

Development of this module will start in late-summer 2016 and continue for the following year. It is anticipated that the module will have the units: *Unit 1: Introduction to GPS, Unit 2: Static GPS survey design, Unit 3: RTK GPS survey design, Unit 4: Surveying surface change, Unit 5: Surveying geomorphic features, Unit 6: GPS data processing*, and *Unit 7: Summative Assessment*. The module building process will also include identification of geo-educational "hot spots" where existing campaign GPS benchmarks are in regions used by multiple field courses and have the potential to show detectable change on research topics such as earthquake, volcanic, and landslide hazards or fluid-withdrawal land subsidence. Field courses could choose to integrate annual resurveys into the curriculum to support long-term research. For example, over several years a Central Washington University field geodesy course resurveyed benchmarks in volcanic provinces to detect magma movement (see Melbourne letter). For

RTK GPS, the module will suggest recommended field site parameters for investigating questions related to fault scarps, channel form, glacial moraine structure, and more. Once Module 2 has been developed and tested, the project will run short courses and workshops to facilitate faculty adaption and adoption of the resources.

3.3 Development methodology. This project leverages the UNAVCO GAGE facility and the accessibility to instrumentation (GPS receivers and antennas, and TLS equipment) as well as the vast technical expertise and knowledge of the UNAVCO field engineering staff. The community collaborators from Indiana University and Idaho State University bring significant expertise in both geodetic field instruction [Douglas, 2012] and research [Barnhart and Crosby, 2013]. Both will collaborate on both modules, but Dr. Douglas will be the lead author of the remaining Module 1 components and lead instructor for the related short course and Dr. B. Crosby will lead on Module 2 development and dissemination. A full introduction to the project's development process and pedagogical considerations will be given to Dr. B. Crosby and the two graduate students in late-summer 2016 by Drs. Pratt-Sitaula and Douglas, drawing on experience with the GETSI (GEodesy Tools for Societal Issues; http://serc.carleton.edu/getsi/index.html) project. The GETSI project is developing student learning materials that integrate geodetic data into important societal contexts. GETSI is using a development model established by the SERC-led InTeGrate project that includes a Materials Development Rubric and Timeline system of Checkpoints to ensure high quality products (http://serc.carleton.edu/getsi/ info_team_members/timeline.html). The established relationship between UNAVCO, Indiana University, and SERC, through the GETSI project, will greatly facilitate the efficient development and dissemination of high quality field-oriented learning modules.

Both modules will be designed to specifications of the Field Geodesy Materials Development Rubric, which will be slightly modified from the GETSI and InTeGrate rubrics. Four overarching "Guiding Principles" will require the modules to include: 1) addressing of one or more societal "grand challenge/s" in health/safety, environment, or resource issues [Davis et al., 2012; Jones Kershaw and NRC, 2005; NRC, 2001]; 2) field geodesy data collection and analysis; 3) geoscientific communication and habits of mind; and 4) quantitative skill development. In addition, the rubric elements guide the developed materials to have high quality design characteristics including: learning goals, assessment, resources/materials, instructional strategies, and overall alignment.

This structure promotes a backwards design [Wiggins, 2005] approach in which authors first consider what big ideas and skills they would like students to gain and then align learning objectives, instruction, and assessment around these goals. Research-based teaching practices such as activities that scaffold from novice to advanced levels and opportunities for reflection and synthesis are supported through the use of the rubric. In addition, framing science learning in terms of issues for which students can see societal and personal importance lies at the heart of current efforts to transform undergraduate STEM education [NRC, 1999; PKAL, 2006]. Increasing the use of inquiry methods, critical thinking, authentic data, and quantitative reasoning are key steps in the process [Bralower et al., 2008; Manduca and Mogk, 2002; Mosher et al., 2014; NRC, 2011b; PCAST, 2012; Steen, 2001].

This field education geodesy project will also leverage specific lessons learned from the GETSI project. These lessons have been codified into a *Geophysics Curriculum Developer's Manual* and are distributed to the community via the GETSI website. In brief, it is essential to combine a triptych of expertise in: 1) geodetic and data processing, 2) undergraduate instruction, and 3) pedagogy and assessment. Many times faculty members think that simply being an undergraduate instructor is sufficient for quality curriculum development; it is widely recognized that pedagogical knowledge is also key at any level of instruction [Magnusson et al., 1999; Gess-Newsome & Lederman, 2001; Luft et al., 2004]. However, far fewer projects seem to recognize the critical value of fully integrated content and data expertise into the development team. This seems to be particularly important for processing-intensive geodetic methods. GETSI found that ideally a content expert is actually a co-author. When this is not feasible, thoughtful cultivation of committed "technical experts" can also serve well [Cronin et al., 2012]. Needed within the "geodetic expertise" is actually considerable time for various data management and geodetic instruction manuals. GETSI found that graduate student interns could give significant support to faculty authors. However, the short duration of a summer internship somewhat limited progress. Therefore, with the Field Geodesy Education project, a summer intern and two academic-year graduate students will be involved in the project to provide technical support.

3.4 Module testing and assessment. After a module passes the Field Geodesy Materials Development Rubric, it will be ready for course testing. Modules will be tested in classes and field courses of three instructors. We have included honoraria for the non-author testing instructors into the budget. Dr. Pratt Sitaula will facilitate the external testing process.

During module testing, students will take the pre & post InTeGrate-developed Geoscience Literacy Exam (GLE) and attitudinal survey (http://serc.carleton.edu/integrate/info_team_members/ currdev/ course_status.html#firstweek). These data will inform the Field Geodesy project and be folded into a much larger InTeGrate analysis of students countrywide. As one of the few InTeGrate-affiliated projects that targets majors-level students (GETSI is half majors-level), the data from this proposed project will provide valuable counterpoint to the introductory level findings. In addition to the surveys, the final student summative assessment will be collected and analyzed for achievement of the module goals and guiding principles for both the assessment itself and student work. Students will be informed of the study and have the chance to opt out of having their data included but they will be required to do all the same work. Feedback from authors is collected via a series of structured reflections and “Instructor Story” of resource use. Final module revisions will follow student data analysis. Initial Materials Development Rubric and student work evaluations will be done by Dr. Pratt-Sitaula. When she determines that materials are nearly ready, she will inform Ms. Iverson at SERC, who will do an external evaluation. If uncertainty persists, a SERC assessment consultant will be asked to do a further evaluation.

The TLS components of Module 1 have already passed an UNAVCO internal evaluation based on the rubric, but upon the start of this project, SERC will do an independent evaluation and make recommendations. The testing process for Module 1 will be somewhat different than standard GETSI procedures or that planned for Module 2. Because the TLS aspects of Module 1 have already undergone (internal) student data analysis and several iterations of revision, the authors will not be the ones to further test the module within this project. Instead, three participants in the *High Resolution Topography* short course (late summer 2016) will be solicited to implement module materials (see letters from Niemi/Clark, Wang, and Ward). They will be given a fair amount of leeway on how to use the module. Part of the project analysis will be to investigate *how* they choose to adapt and adopt the materials for their particular field setting. Their experience will be captured in a structured reflection and published as a mini “Instructor Story” to provide further examples for future adopters. This investigation will inform future development and dissemination efforts by providing insights into the adaption/adoption process.

Module 2 will proceed with more standard course testing by both authors and a third pilot-tester from a different type of institution/course. Dr. Bob Wang, from minority-serving University of Houston has committed to testing at least one of the modules. His more urban field setting will provide good diversity from the rural “field camp” programs at other institutions. Dr. Lucas Ward, from Rocky Mountain College has also committed to testing the modules. Dr. Ward participated in the Geodesy Field Education Workshop at UNAVCO in 2014 and is a UNAVCO community member.

3.5 Faculty training and professional development. This project will provide resources for faculty to incorporate instrumentation and cutting edge technologies into their classes and field experiences. Research shows that for faculty to be effective in incorporating technologies they need to not only become familiar with that technology but also realign their teaching practices and student outcomes [Keengwe et al., 2009; Sunal, 2001]. After student learning materials and instructional guides are completed, we will lead short courses for faculty. These short courses will include training on the module topics, guidance on using the instrumentation, and instruction on best practices in field instruction when incorporating the module units into the course curriculum.

UNAVCO has extensive experience in facilitating and leading education-focused workshops for faculty at the Geological Society of American (GSA) annual meeting, at UNAVCO headquarters in Boulder, and nationally in collaboration with partner organizations. Recruitment of faculty for participation in training workshops and short courses will be key. UNAVCO has an existing community of faculty interested in geodesy field education. In addition to this group, we will advertise the professional development opportunities through SERC listservs (general and field education), UNAVCO listserv, American Geological Institute (AGI) field camp directors listserv, at the American Geophysical Union (AGU) Fall Meeting (where UNAVCO has an exhibit booth) and through personal networks.

A short course for units in the *Analyzing High Resolution Topography* module will be held at the Indiana University Geologic Field Station (IUGFS) in late summer 2016. As five of the units were prepared and tested in summer 2015 as part of a proof of concept project for this proposal, revisions and development of the remaining two units will be completed prior to the faculty short course. The short course agenda and content will be developed in June and July. In August 25 faculty will travel to the IUGFS for a four day, three-night workshop. The workshop will focus on instruction of best practices for integrating instrumentation into courses and will include hands-on instruction with TLS instruments with the support of UNAVCO technical staff and education specialists. A second workshop focused on instructional best practices will be held at the 2016 Annual GSA Meeting in Denver. This GSA short course will complement the annual introductory technical short course on TLS data collection UNAVCO leads each year.

Faculty training workshops for the *High Precision Positioning* module will take place at UNAVCO headquarters in Boulder, Colorado in fall 2017. The workshop will focus on GPS instrumentation (static and RTK) and instructional best practices for using GPS in field education. UNAVCO has an array of GPS technologies available and field engineering staff will assist with the technical portion of the workshop. Education specialists will provide instruction on best practices. UNAVCO agrees to sponsor a short course at GSA in 2017 (Seattle, Washington) to disseminate the *High Precision Positioning* module to a broader audience. UNAVCO agrees to provide funding for the GSA 2017 short course as well as the summer 2017 professional development workshop in Boulder.

Once faculty have completed an instruction-focused workshop, they will be eligible to request support from UNAVCO for integration of technologies into their courses or field experiences. As a science research facility, a core activity of UNAVCO is individual support for faculty. Traditionally this support has focused on scientific research but is being extended to faculty for education and outreach activities. Requests will be made through the UNAVCO Project Support Request (PSR) form on the UNAVCO website. Faculty requesting field education support will submit an addendum to their PSR. The addendum includes questions that will provide insight into their pedagogical approach and expected student outcomes. UNAVCO will solicit requests annually with a deadline of February 1 after which requests will be evaluated by education and technical staff and prioritized based on a number of factors (e.g., quality of addendum, availability of resources for the time of request, funding source). Supported faculty will be required to fill out a post-field education experience evaluation from which we will gain information both about the process of the support experience as well as the field experience for their students. Typically field courses will have to pay transportation and room/board costs for requested field engineer and/or equipment; but all salary costs will be paid by GAGE (geodetic facility run by UNAVCO).

3.6 Education research. Research documenting best practices in undergraduate field instruction in higher education and student learning gains around field experiences is lacking. Huntoon et al. [2001] examined the effects of field based teaching on teachers; and instructional methods in higher education are documented [Macdonald et al., 2005]; but little research has been done to formally investigate how faculty teach in the field and how that impacts student learning. High quality field instruction is a much more difficult task than might be thought [Kober, 2015]. The transition from fieldwork-for-research to teaching students in the field requires adaptations and changes to ones concepts of being in the field. We recognize the need to contribute to the scholarship of geoscience education through examining faculty field instruction techniques and how students increase their content knowledge through field experiences. Well-designed learning modules for use in the classroom or in the field will enable faculty to help students both gain experience setting up and using the instrumentation for data collection as well as experience manipulating data and interpreting it.

From the perspective of research on student learning, we ultimately want to know “Does the incorporation of geodetic technologies in field experiences increase student learning?” Research on the effect of incorporation of technology on student learning in field experiences is limited. Much of the existing literature is focused on specific field techniques, such as mapping [Abolins, 2014; Kelley et al., 2015] or general experiences [Feig, 2010; Pearce et al., 2010; Todd & Goeke, 2012]. Student learning is influenced by many factors, some of which include self-efficacy [Chemers, 2001] prior content knowledge [Pintrich, 2004], cognitive skills [McConnell et al., 2003], interest in the topic being taught [McConnell & van Der Hoeven Kraft, 2011; van der Hoeven Kraft et al., 2011] as well as effectiveness of instruction [Umbach & Wawrzynski, 2005]. Through this limited project we cannot address all the elements critical to this broad question, but we can begin to collect the foundational data to help us explore this research question with a focus on faculty instruction.

We will use this project to collect baseline data on how faculty implement and adapt materials for inclusion into their own field education courses. The effective adoption of teaching materials created by someone else is often a difficult process. As Henderson and Dancy [2008] found, physics curriculum development and dissemination has had minimal influence on the teaching practices of physics faculty. It is critical that through this project, we develop consistent materials that not only expose students to field geodesy, but will be a resource to geoscience faculty across the country. In geology, the MARGINS "mini-lesson project" [NSF, 2011] is a collaborative effort to bring together faculty to develop curricular resources to educate and engage geoscience students, with results on implementation pending. The materials created under our project follow a strict development and testing rubric with clear learning objectives for students. It is critical to know how the existing materials are adapted for implementation into field experiences at different colleges and universities given that all faculty have slightly different constraints (time, resources) and likely a different orientation to teaching style and philosophy.

Data collected include a faculty reflection and professional development survey. The faculty reflection will be based on the existing GETSI assessment (based on InTeGrate) and expanded to capture faculty teaching philosophy as it relates to field instruction, faculty field instruction experience, motivation for including geodetic technologies into field experiences, understanding of best pedagogical practices, and summative thoughts on the successes and challenges of incorporating pre-made materials into their courses. The reflection will be administered pre- and post-instruction. Faculty developers (PIs B. Crosby and B. Douglas) will test the modular units in their field courses. Each will complete a faculty reflection post-testing. Faculty reflections will be collected from Drs. Ward, Wang, Niemi, and Clark (see letters) as they test materials. We will recruit additional faculty (and pre- post-reflections) to test materials as necessary, collecting based on assessment recommendations from SERC. Beyond the authors and faculty testing modules, we will provide professional development for faculty through short courses at GSA and workshops at the UIGFS and UNAVCO Headquarters. All faculty who participate in these professional development opportunities will complete pre-post surveys to obtain baseline data on their pedagogical content knowledge, field instruction experience, and expectations around the implementation of these curricular modules into their own instruction. Beyond the scope of this project would be the administration of pre- and post-faculty reflections to all instructors who incorporate the materials into their teaching after participating in the professional development. Data collection will be facilitated by SERC with additional input from Drs. Pratt-Sitaula and Charlevoix, as needed.

3.7 Dissemination, Sustainability, and Next Steps. Final modules will be available online through the SERC-hosted GETSI website (summarized above) and linked from the UNAVCO website. SERC, NAGT, and UNAVCO have an extensive media networks used to share information and resources. UNAVCO is also partnered with geoscience organizations that further share content and resources through social media and other venues (AGI, AGU, GSA, OpenTopography, Federation of Earth Science Information Partners (ESIP), International Association for Geoscience Diversity (IAGD), and Pacific Northwest Seismic Network (PNSN), among others). After modules are published an organized social media campaign will be disseminated through the UNAVCO Outreach Specialist to reach partner organizations.

The primary mechanism for dissemination will be the GSA short courses and the professional development training sessions in the summers of 2016 and 2017. Here faculty will be trained on implementation and encouraged to share the resources with their colleagues. Beyond the timeline of this project, the materials will continue to be taught in UNAVCO-led short courses at GSA. UNAVCO has a long history of providing education-focused short courses, as well as technically focused short courses on GPS data processing and TLS. We will share these educational modules with the technical short course instructors; Charlevoix and Pratt-Sitaula will facilitate the process of working with the technical short course instructors to incorporate some element of the modules in the technical short courses, if only to exposed participants to the educational applications of the technologies and data. In addition, UNAVCO hosts a biannual Science Workshop for the geodetic community. A Special Topics Session will be organized at the 2018 UNAVCO Science Workshop focused on the field education materials developed through this project.

At least one, and likely two, peer reviewed publications will be written by the project team and submitted to the Journal of Geoscience Education, In the Trenches, or similar. We envision a paper focused on the modules and the module content and a second outlining the knowledge gained through researching faculty implementation and adaptation of the modules in their own courses and field camps.

We anticipate strong adoption of the modules by the UNAVCO and broader geoscience community and incorporation into the UNAVCO Project Support Request system as described in Section 3.5. As TLS and GPS technologies evolve, UNAVCO will incrementally update portions of the modules through the dedicated staff in the Education and Community Engagement program and with the technical assistance of field and data engineers. This is an important and critical element to the sustainability and continued relevance of the materials developed. With the module infrastructure in place, updates to technologies (instrumentation, data, data products) will be relatively easy to do. The IUGFS is also committed to further training of faculty and will support one interested faculty member from the academic community each summer during the field geodesy week as they have done several times in the recent past.

Beyond this project. Looking ahead, Unmanned Aerial Systems (UAS) are rapidly emerging as a platform for geoscience research data collection. As more geoscience researchers implement them into their research program, we expect that there will be interest in integrating these platforms into education as well. Presently, the regulatory framework for UAS operations in the USA is complicated and evolving, but we anticipate that facilities such as UNAVCO will play a role in supporting this technology in the future. Conveniently, educators working with lidar or SfM data collected from a UAS platform could easily use several of the units in the *Analyzing High Resolution Topography* module. Should UAS emerge as expected in the coming years, UNAVCO will update the curriculum to include appropriate units around SfM and lidar data collected from these platforms.

At the conclusion of an “exploratory” project, we will have a solid curricular foundation of modules, valuable experience in dissemination, and baseline data on faculty implementation into diverse field settings. We anticipate that further “implementation and development” will be needed to build on this preliminary work – including a significant effort for broader dissemination, engineering and equipment support, and a rigorous investigation of the effectiveness of these materials in improving student learning and faculty instruction in field education settings. Educational field geodesy support beyond potential IUSE funding is under consideration by the GAGE facility pending successful implementation of these activities. Sustainable facility support would include annual short courses for faculty at the GSA annual meeting and at least one professional development course at the UNAVCO headquarters in Boulder. UNAVCO would also contribute staff time for field engineering and data engineering technical support for field courses and educational materials revision as technologies evolve and units require revision.

4. MANAGEMENT PLAN

Figure 2 outlines the program structure and primary program components and responsibilities. The overarching goal is to improve student learning in field education. Overall programmatic evaluation is provided by SERC. Dissemination of final products will be led by UNAVCO Education and Community Engagement (ECE) program using a variety of channels including SERC and the National Association of Geoscience Teachers (NAGT) (see letters). The technical expertise for the project will be provided by UNAVCO from their field engineering and data engineering staff. UNAVCO ECE also has expertise in both geodesy and education. Short course instruction efforts will be led by Dr. B. Douglas and Dr. B. Crosby. They will be the primary content developers and will incorporate materials into their classes. Additional content testers (Ward and Wang, among others) will provide additional information on individual units for modules. Assessment efforts will be led

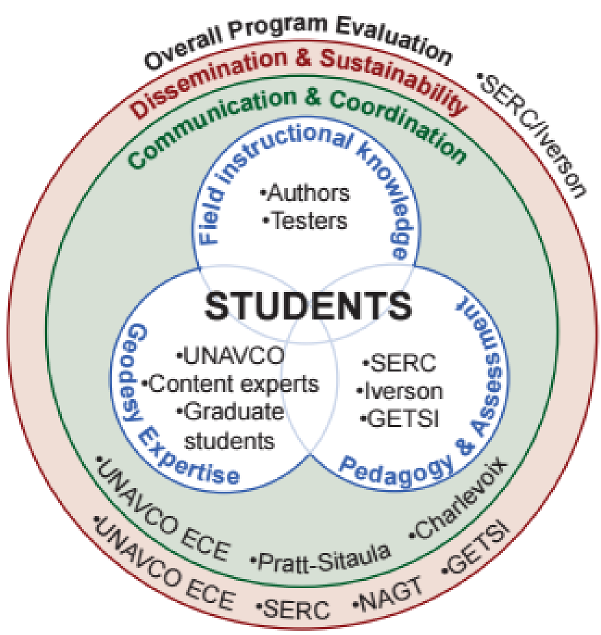


Figure 2. Program structure and responsibilities.

by SERC drawing on lessons learned from the GETSI project and facilitated in part by Dr. Pratt-Sitaula. Dr. Charlevoix will assist with analysis of the research data.

4.1 Project Team. PI. Dr. Donna Charlevoix is the Director of the UNAVCO Education and Community Engagement (ECE) program, of which community support for instruction is a key element of the portfolio. The ECE program provides infrastructure for geoscience and geodesy learning and has extensive experience engaging teachers, K-20 students, university faculty and researchers. UNAVCO manages the curriculum development project Geodetic Tools for Societal Impact (GETSI) on which this project's module design is modeled. Dr. Charlevoix will lead UNAVCO efforts. Charlevoix has over 20 years of high education instruction and curricular design, formal expertise in science education and research, and over five years managing domestic and international science and education programs including science teacher professional development programs and working with scientists from all disciplines within geosciences. Dr. Charlevoix will supervise the project activities at UNAVCO and ensure that the necessary UNAVCO resources and support are available and assist with the education research.

Co-PI, Project Manager. Dr. Beth Pratt-Sitaula brings geoscience, educational, and logistical expertise to the project. She is the Project Manager for GETSI and as such is intimately acquainted with the module development and assessment process. She helped develop the prototype TLS learning module. She also teaches *Nepal: Geoscience in the Himalaya* (www.sit.edu/npg) field camp program in the summers, giving her first-hand experience with the challenges and benefits of geoscience field education. She helped install a GPS network in Nepal [Galetzka et al., 2015], was a CoPI on an NSF-MRI proposal which purchased a terrestrial LiDAR scanner (TLS) for student and faculty use, and has been a CoPI on other education projects within NSF EarthScope and NSF GK-12. Prior to joining UNAVCO as an Educational Specialist, she held a joint position at Central Washington University (CWU) in the Geological Sciences and Science Education Departments.

Co-PI, Faculty developer. Idaho State University (ISU), designated by the Carnegie Foundation as a High level Research University, has partnered with UNAVCO for over a decade on numerous projects including measuring landslide deformation with geodetic GPS [Chadwick et al., 2005] and permafrost thaw with TLS [Barnhart and Crosby, 2013]. Dr. Benjamin Crosby (PI) began working with lidar data at its emergence in 1993. During his 8 years at ISU, he has supervised 14 graduate students and 6 undergraduate theses, each of which depended on analysis of high-resolution topographic data. Crosby leads ISU's digital field mapping program and has been developing this curriculum since his PhD (web.mit.edu/12.114/05_fall/www/tutorials.htm). During this project, graduate student mentoring will include pedagogical training from UNAVCO staff, a teaching practicum at ISU, and networking through the AGU Education focus group. Through ISU's DA program, the student will be immersed in a community of other graduate students focused on becoming strong educators. ISU Geosciences' existing curriculum emphasizes the geotechnologies, offering 2 summer field courses, 8 courses in GIS, 3 in remote sensing, and 2 specifically regarding GPS and geodesy. Digital field mapping has been an integral component of ISU's internationally subscribed field courses since 2004. Faculty members Drs. Link, Delparte, Bottenberg and Pearson have enthusiastically committed to testing our curriculum modules in their geology or geotechnology courses (see letters of collaboration).

Co-PI, Faculty developer. Indiana University (IU), a Research-1 institution and founding member of UNAVCO, has multiple faculty members engaged in geodesy research and education. The Geological Sciences Department's long-term commitment to inquiry-based, technology- and data-focused education for both STEM and non-STEM students makes it particularly well suited for this project. Also, IU has adopted a unique geographically based admissions policy that aims to ensure wide representation of Indiana's residents (from elite communities to inner city zones to rural poor); thus UI students are from more diverse socioeconomic backgrounds than is typical for a premier state university. Dr. Bruce Douglas (PI), who will head IU's involvement, has been involved in developing and teaching >30 laboratory modules for introductory physical and environmental geology courses and majors' field camp geology in the last 5 years. During the development of the introductory lab exercises, he worked closely with School of Education colleagues on pedagogical design and embedded assessment. A major component of the recent field camp curriculum development was a weeklong module featuring TLS, a powerful new geodetic tool [Douglas et al., 2009]. Previously, Douglas developed an instrumented watershed at the field camp along with curriculum centered on the technology and data from the watershed. Two other IU faculty members, Dr. Michael Hamburger and Dr. Kaj Johnson, have significant background in geodetic research and with UNAVCO ECE. They have committed to testing, or reviewing for content accuracy as needed (see Johnson letter). IU has at least three introductory (physical geology, earthquakes and volcanoes, and environmental geology) and two majors-level courses (structural geology and applied geophysics) that would use modules developed by this project in addition to use in the field courses offered from the IUGFS.

Evaluator. Ellen Iverson is SERC's Director of Evaluation and has worked for SERC since 2003. She has been evaluator for more than 25 science education projects and co-leads the national assessment efforts for the SERC-led InTeGrate STEP Center. Her work includes Evaluator for the GETSI project and thus she has prior experience with UNAVCO, Indiana University, and geodetic applications.

Technical experts (Senior Personnel). Expertise in the geodetic technologies that are the focus of this proposal will be provided by UNAVCO staff. Christopher Crosby (UNAVCO Geodetic Imaging Project Manager and Co-PI of OpenTopography) will provide technical guidance for Module 1 (Analyzing High Resolution Topography). Over the past four years Crosby has taught TLS in eleven different field courses. He has more than a dozen years experience working with high resolution topography from lidar. Support in GPS technology for Module 2 (High Precision Positioning) will be provided by field engineers from the UNAVCO PI Project Support group managed by Jim Normandeau. Mr. Normandeau has over two decades of experience deploying and installing high precision GPS instrumentation in support of a wide range of scientific applications. In addition to field support, UNAVCO will also provide technical support related to data processing and interpretation.

Graduate student assistants. Graduate student assistants will help with module development by collecting background materials, processing data, formatting content, and supporting short courses and field testing. The ideal students will have a strong interest in geoscience education as well as geodetic technologies. The project will start with a graduate intern from the 2016 UNAVCO Summer Internship Program (USIP), who will initiate GPS materials development and support SfM finalization. One graduate student will be mentored by Dr. Crosby at ISU and work primarily on GPS-related data and supporting instructor resources for *Module 2: High Precision Positioning*. Another will be mentored by Dr Douglas at IU and be responsible for assembling an archive of existing TLS and SfM data files and supporting instructor manuals for *Module 1: High Resolution Topography*. All graduate students will be mentored in pedagogy and high quality learning materials development, as well as technical geodetic aspects.

4.2 Timeline. Table 1 outlines the timeline of work to be completed for this project including instructional modules, research and evaluation, and dissemination. The development of TLS-focused materials (Module 1, units 1-5) was completed and tested in summer 2015. This 5-unit suite of materials will have some revisions, based on SERC recommendations, and will be finalized in early summer 2016. Materials will be published online prior to the August 2016 faculty professional development workshop. Module 1 units focused on SfM will begin in summer 2016 and continue into fall as needed. Unit testing will occur in spring 2017 with revisions finished and published in time for the fall GSA faculty short course. Formal support requests from community members will be accepted starting fall 2017 for the 2018 calendar year (field and classroom support).

Development testing and publication of units for Module 2 (*High Precision Positioning)* is a continuum starting in fall 2016 and continuing through the duration of the project. Development will begin fall 2016 and continue into summer 2017. Author testing of the first three to four units of Module 2 will occur during spring 2017. Collaborating faculty will test additional units in summer and fall 2017 depending on how quickly the development process proceeds. Revisions will be made immediately after testing with units published as they are finalized in fall 2017 and spring 2018.

Formative evaluation by SERC will occur at the end of the first year so corrective measures can be introduced if needed. Summative evaluation will take place at the end of the project. Research instruments (faculty reflection and professional development survey) will be developed and finalized at the beginning of the project. Faculty reflections will be administered pre- and post-testing of the various units. Exact timing will depend on faculty teaching schedule. The professional development survey will be administered before and after each GSA short course each fall. Full data analysis of faculty reflections and surveys will occur each spring.

Dissemination includes faculty professional development at summer workshops and GSA short courses following the publication of modules. Project results will be presented at GSA and/or AGU fall meetings in 2018 with peer-reviewed publication following.

Table 1. Project Timeline including instructional modules, research, evaluation and dissemination.

		Year 1 (2016-17)			Year 2 (2017-18)		
		Summer	Fall	Spring	Summer	Fall	Spring
Instructional Modules							
Development	TLS						
	SfM	[green]	[green]				
	GPS		[purple]	[purple]	[purple]		
Testing (+assessment)	TLS						
	SfM			[green]			
	GPS			[purple]	[purple]	[purple]	
Revisions	TLS	[red]					
	SfM				[green]		
	GPS				[purple]	[purple]	
Finalize & publish online	TLS	[red]					
	SfM					[green]	
	GPS					[purple]	[purple]
Research & Evaluation							
Program evaluation				[blue]			[blue]
Develop instruments		[blue]	[blue]				
Administer faculty reflection				[blue]	[blue]	[blue]	
Administer PD survey		[blue]	[blue]		[blue]	[blue]	
Data analysis				[blue]			[blue]
Dissemination							
Faculty professional development	TLS	[red]	[red]				
	SfM				[green]	[green]	
	GPS					[purple]	[purple]
Support community requests	TLS			[red]	[red]	[red]	[red]
	SfM						[green]
	GPS						[purple]
Geoscience conference						[gray]	
Publication							[gray]

- [red] TLS - Module 1: units 1-5
- [green] SfM - Module 1: units 6+
- [blue] Research & Evaluation
- [gray] All Project

4.3 Project Evaluation. SERC will serve as the project's independent evaluator, providing ongoing evaluation and assessment consulting for the overall project. Iverson will lead the evaluation with some input from a SERC assessment consultant. Iverson and the assessment consultant will provide an external perspective on the materials development review and analysis of student data. Iverson will provide final review of all learning modules (formative assessment), student data (summative assessment for Project Goal 1), and faculty reflections and "stories" (summative assessment for Project Goals 2 and 3). SERC will utilize the Geoscience Literacy Exam (GLE) [Ward et al., 2015] to examine student gains. GLE is part of the NSF-funded InTeGrate Project and results will contribute to broader insights from this exam. The assessment process is described in Section 3.4. Student learning assessment data will be collected to evaluate the success of the materials in meeting standards of effective design and achieving learning goals. SERC will provide a critical external perspective on assessing both the quality of the materials in meeting the goals of the project and using evidence-based teaching practices, as well as the alignment of the student learning assessments to those materials. SERC will also oversee the development of faculty reflection forms. Faculty will submit these structured reflection forms post-instruction and they will be analyzed with a focus on the use and implementation of the modules in different field education contexts. Finally, SERC will provide annual external evaluation reports to be submitted to NSF as a part of the annual review.

5. BROADER IMPACTS OF PROPOSED WORK

There is a strong need for integration of geodesy into undergraduate geoscience instruction. In particular, geodetic field technologies can be applied to a broad range of societally critical geoscience topics such as hazard assessment, as well as non-academic, commercial and governmental sector applications. The materials developed through the proposed project will be a resource to the geodesy community, geoscience educators, and potentially faculty from other disciplines that incorporate geodetic technologies and instrumentation in their work. The design of this project as "modules" with individual units selected for incorporation into an instructor's curriculum has the potential for widespread adoption and adaptation. During this two-year project at least 240 undergraduate geoscience students will be directly impacted. As the materials are adopted by additional faculty after the professional development workshop the number of students exposed to these geodetic technologies will grow to several thousand. The skills students will build through participating in field experiences that integrate geodetic technologies will be important in their future careers and life outside the geosciences.

In addition, during the process of module development two geoscience faculty authors and two supporting geoscience graduate students will received considerable professional development on high quality curriculum development, and on the order of 100 geoscience instructors will receive training on technical and pedagogical components of geodetic field teaching. Collaborator Dr. Ward (letter) has indicated that he will be sharing his knowledge and some of the units via outreach he does to a K-12 teacher classroom. We anticipate that other instructors we train will also share their knowledge with audiences beyond the undergraduate community.

6. RESULTS FROM PRIOR NSF SUPPORT

UNAVCO Community Proposal - Geodesy Advancing Geosciences and EarthScope: The GAGE Facility (10/1/2012 to 9/30/2018)

- EAR-1261833. $92,154,662. PI: M.M. Miller, Co-PI: D. Charlevoix, G. Mattioli, C. Meertens.

Summary: The GAGE Facility: Geodesy Advancing Geosciences and EarthScope Cooperative Agreement (CA) supports advancement of cutting-edge community geodetic research around the world.
Intellectual Merit: Geoscientists using global geodetic infrastructure coupled with leading edge techniques are well poised to advance basic research that is in the U.S. and global public interest as the challenges of living on a dynamic planet escalate. Space geodesy furthers research on earthquake and tsunami hazards, volcanic eruptions, coastal subsidence, wetlands health, soil moisture and groundwater distribution. Of particular importance are contributions to understanding of processes related to climate dynamics, including hurricane tracking and intensity, sea level rise, and changes in mountain glaciers and large polar ice sheets.
Broader Impacts: This project supports fundamental research into natural hazards spanning multiple disciplines. As global population disproportionately increases in hazards-prone coastal and tectonically active regions of the US and across the globe, the societal relevance of quantifying, understanding, and potentially mitigating natural hazards grows.
Publications: Berglund et al., 2015; Charlevoix & Morris, 2014; a full community bibliography is available at the UNAVCO website (www.unavco.org)

Collaborative Research: Geodesy curriculum for the 21st century--Innovative science for addressing societally critical issues (7/1/2013 to 6/30/2016)

- DUE-1245025 (UNAVCO) $194,583. PI: M.M. Miller, Co-PI: B. Pratt-Sitaula, D. Charlevoix.
- DUE-1245153 (Indiana University) $46,394. PI: B. Douglas

Summary: This project develops, tests, revises, and disseminates curricular modules that address important societal issues through student investigations using geodetic data.
Intellectual Merit: This project is the largest undergraduate geodesy curriculum effort to date, the first strongly grounded in STEM educational research and student learning assessment, and the first to feature newer applications (climate change, water resources) alongside more traditional ones (earthquake/volcanic hazards, tectonic plate motions).
Broader Impacts: This project benefits society by arming young people (many from underrepresented groups) with greater knowledge of how science research can inform societal decisions. The undergraduate curriculum materials featuring geodesy supports overall Earth science literacy gains.
No publications were produced under this award (outside of abstracts).

Collaborative Research: Spatial and Temporal Influences of Thermokarst Features on Surface Processes in Arctic Landscapes. (09/01/2008 - 08/31/2013)

- ARC-0806399 (Idaho State University) $251,570. P.I. B. Crosby

Summary: This project examines the formation and evolution of thermal erosion features in Arctic Alaska and their implications for terrestrial and aquatic ecosystems. Crosby's responsibility was to document the topographic evolution of these features and the rates of sediment production.
Intellectual Merit: This project, for the first time, applied terrestrial and airborne laser scanning recognize undetected features and track their topographic evolution, tying their geometry to both hydrometerological drivers, local substrate and landscape position. Over 120 scans were completed and 7200 features were identified.
Broader Impacts: Supported 5 graduate (all completed theses) and 3 undergraduate researchers, 9 manuscripts published (1 in Nature, 1 in Science), 3 under review and 15 conference presentations. Led to involvement in NSF's Permafrost Carbon RCN and mentorships in the Permafrost Young Researchers Network. Findings were incorporated into a multi-agency steering document for the Arctic LCC. Hydrologic, geomorphic and topographic data is now available on LTER, ACADIS, UNAVCO and HIS distribution centers.
Publications: Krieger and Crosby, in review; Barnhart et al., in review; Jensen et al., in review; Pelletier et al., 21015; Bierman et al., 2014; Jensen et al., 2014; Crosby and Martin, 2013; Barnhart and Crosby, 2013; Schuur et al., 2013; Bowden et al., 2012; Schuur et al., 2011; Rowland et al., 2010

Enhancing Learning of Science Categories Through Guidance of Psychological Models of Classification (9/15/2015 to 8/31/2018)

- DRL-1534014 (Indiana Univ) $946,386. P.I. R. Nosofsky, Co-PI: B. Douglas, Co-PI: M. McDaniel

Summary: This project will extend formal models of category learning to guide discovery and evaluation of training regimes that promote efficient learning of natural scientific categories (*e.g*. rock types) and that enhance students ability to generalize correctly to novel members of those categories.
Intellectual Merit: Because categories are the building blocks of human thought and reasoning processes, the teaching of science categories is a core component of all science education curricula. It is only recently, however, that investigators have begun to investigate factors that may facilitate the instruction of natural science categories. Furthermore, these empirical investigations are not strongly motivated by the advances in formal modeling that have taken place in cognitive science. The present project will introduce a major innovation by using successful formal models of human classification to help guide the search for the training regimens that lead to the most efficient learning and generalization performance.
Broader Impacts: The work will provide a substantial theoretical and empirical foundation that could significantly inform and improve instructional practice for assisting students' learning of science categories. Such focus on learning science categories aligns with educational objectives in science classes from college level and beyond. Yet, teachers tend not to receive any formal training about the possible importance of guiding students' exposures to particular category instances or sequencing of those instances. Thus, the results of the project will inform and potentially improve standard practice in teaching science categories, and by so doing assist society's efforts to promote STEM education.
No publications were produced under this award (outside of abstracts).

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