Geodesy curriculum for the 21st century: Innovative science for addressing societally critical issues

Recent technological innovations in geodesy (the measurement of the size, shape, and mass distribution on Earth and changes over time) have allowed a wide range of advances in our understanding of Earth processes on topics critical to society such as natural hazard mitigation, climate change, and water resource management. Undergraduate teaching resources have not kept pace; thus this project’s objectives are: 1) improve geoscience (particularly geodetic) knowledge base of undergraduate students both for general science literacy (introductory) and future science workforce (majors-level) and 2) improve effectiveness of teaching resources and pedagogy employed by faculty members teaching geodesy, geoscience, and allied sciences.

Intellectual Merit
GEdody Curriculum for Undergrads (GECU) proposes to develop, test, revise, and disseminate curricular modules that address important societal issues through student investigations using geodetic data. GECU will be 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). Lessons learned can inform future curriculum development featuring authentic data (both geodetic and other) and will be codified in a Developer’s Manual to be disseminated with the curricular modules. The GECU partnership includes a university consortium (UNAVCO), community college (Mt San Antonio College), university (Indiana University), a STEM education center (Science Education Resource Center [SERC]), and geoscience educators professional organization (National Association of Geoscience Teachers [NAGT]). In keeping with research-based best practices, modules will include inquiry activities using authentic data, quantitative skill development, small group learning, measurable outcomes, and embedded assessments. Module design teams will bring together instructional, geodetic, and assessment expertise to produce high quality materials that marry cutting edge research discoveries with effective classroom practices. To ensure ease of adoption at different sites, modules will be tested in at least three institutions, one or more of which include significant numbers of students from underrepresented groups. SERC will evaluate the overall program using student learning gain data and faculty use metrics.

Broader Impact
The project will benefit society by arming young people (many from underrepresented groups) with greater knowledge of how science research can inform societal decisions. Undergraduate curriculum featuring geodesy, an area of recognized need for improvement, will support overall Earth science literacy gains. GECU will leverage previous and ongoing investments by NSF through SERC’s InTeGrate project and UNAVCO E&O. It shares with InTeGrate a strong grounding in societal issues and thus will utilize many of the same techniques and assessments. Rapid widespread availability of the modules and developer’s manual will be ensured by publication on the well known SERC website (nearly 4 million visitors per year). Besides being housed in a geodesy-specific collection, they will be linked to Teach the Earth, InTeGrate, Cutting Edge, Quantitative Skills, and Using Data sites as appropriate. Dissemination will target both geodesy and larger geoscience instructional communities and seek to engage participants in community building across institutional lines. Efforts will include webinar series, talks/posters at meetings, inclusion in workshops, and news article (EOS or In the Trenches). The latter will be a particularly powerful venue for bringing together module authors and content experts with a broad spectrum of geoscience educators. This curriculum, grounded in geodetic knowledge and high quality pedagogical design, will contribute to the paradigm shift in STEM education.
1. Introduction

Over the last two decades, technical advances in geodesy – the study of the size, shape, and mass of the Earth and their changes with time – have revolutionized our understanding of Earth processes and produced discoveries of major societal impact related to climate change, water resource management, and mitigation of natural hazards (Figure 1). Recent discoveries include:

- Global determination of the size and changes in the Earth’s great ice sheets and the processes that control their rapid retreat (e.g., Velicogna and Wahr, 2006)
- Accurate measurement of present-day global sea-level rise (e.g., Nerem et al., 2006)
- Regional and global measurements of groundwater movement (e.g., Ramillien et al., 2008)
- Determination of tectonic plate motions and crustal deformation (e.g., Kreemer et al., 2010)
- Extraordinary imaging of landscapes from laser and radar technologies allowing new detection of landslide zones and fault scarps (e.g., Arrowsmith and Zielke, 2009)
- Greater detection of subsurface volcanic activity through sensitive ground and radar deformation measurements (e.g., Poland et al., 2006)

Teaching resources and textbooks have simply not kept pace with advances in geodesy, both for introductory and majors-level undergraduate courses. At the majors’ level, this gap compromises our ability to prepare future geoscientists (NSF-EHR Goal 1; NSF, 2008) with a necessary full skill set by omitting essential modern tools. At the introductory level, students are unaware of key emerging breakthroughs in understanding many aspects of geosciences and thus are not gaining the scientific and technical literacy needed to be informed citizens (NSF-EHR Goal 3).

We propose a project to develop, test, revise, and disseminate teaching and learning materials that feature geodesy as it is applied to addressing critical societal issues such as climate change, water resource management, and natural hazards. Inclusion of geodetic data in undergraduate curriculum is an excellent avenue for combining societal relevance with investigation of real data and quantitative reasoning; thus making this proposed curriculum transformative and valuable to a wide range of geoscience educators both within and outside of the geodesy community. Modules will be developed for both introductory and majors-level Earth science courses. 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 science, technology, engineering, and math (STEM) education (NRC, 1999; PKAL, 2006). Increasing the use of inquiry methods, authentic data, and quantitative reasoning in STEM education are key steps in the process (Barstow and Geary, 2002; Bralower et al., 2008; Manduca and Mogk, 2002; PKAL, 2006; Steen, 2001). Our project falls primarily under the TUES component of “Creating Learning Materials”, but also contributes to “Developing Faculty Expertise” through engaging faculty members in the development, testing, and use of high quality curricular materials.

GEodesy Curriculum for Undergrads (GECU) project partnership brings together broad expertise from curriculum development to student assessment to scientific research in geodesy. UNAVCO, a non-profit university-governed consortium of 103 U.S. academic organizations, operates NSF’s national geodetic facility and facilitates innovative and relevant academic research around the world. Through UNAVCO’s experienced Education & Outreach (E&O) program, GECU will leverage the large investment made in UNAVCO research science and bring it into the mainstream of geoscience education (NSF-EHR Goal 2). Project partners, Mount San Antonio College (MtSAC), Indiana University (IU), and other collaborators (see letters in Suppl.), have a broad spectrum of undergraduate students and faculty with experience meeting diverse student
learning needs, including those of racial/ethnic and socioeconomic groups underrepresented in science (NSF-EHR Goal 4). The Science Education Resource Center (SERC) has done extensive assessment of student learning and educational project evaluation in Earth sciences and is a recognized online publishing venue for Earth science teaching resources. Assessment instruments and knowledge gained through SERC’s InTeGrate project (NSF-funded STEM Talent Enhancement Program [STEP] Center) will strengthen this project. The well-recognized and influential National Association of Geoscience Teachers (NAGT) will cosponsor dissemination webinars. This strong partnership will ensure that developed materials are centered on student learning needs, scientifically vetted, and usable by and accessible to the broadest range of faculty possible with sustainability well past the end of TUES Type 1 funding.

2. Why geodesy for students?

Nearly every undergraduate knows about GPS and some of its positioning capabilities, but few appreciate that it can be used to measure millimeter-level fault slip rates and thus give critical information for managing earthquake hazard (Figure 1). Everyday tools that are put to use for science create a natural point of entry to engage students. Modern geodesy, a versatile toolbox of technical innovations, began with optical and gravity surveying techniques; over the last two decades the methods have expanded to include an array of on-land, airborne, and satellite-based observations. Land-based GPS stations, receiving signals from the GPS satellite network, measure movements of tectonic plates, volcanoes, landslides, glaciers, and surface deformation.

Figure 1. Examples of geodetic data. A) Velocities from Earth Scope’s Plate Boundary Observatory (PBO) reveal crustal deformation crucial to determining earthquake hazard; B) Changes in regional gravity obtained from GRACE (2002-10) can show changes in ice (ex. Greenland and Antarctica losses) and ground water (ex. Brazil gains). Courtesy of J. Davis; data from http://podaac.jpl.nasa.gov/grace/; C) LiDAR image (left) reveals clear landslide feature (red dashed line) not easily detectable on conventional airphoto (right) (http://www.oregongeology.org).
related to groundwater or oil extraction with millimeter precision. This same deformation can also be mapped across landscapes by differencing satellite radar images (interferometric synthetic aperture radar or InSAR), or locally by physical measurements such as tilt meters and strain meters. Local gravity measurements with gravimeters have been a staple of applied geophysics techniques for decades; but since 2003, the GRACE (Gravity Recovery and Climate Experiment) satellites have provided unprecedented regional-to-global scale detection of mass movements over sub-annual timescales. Seasonal fluctuations and interannual trends in ground water and ice mass give insights into effects of global climate change and water management policies. Satellite altimeter measurements allow global observation of sea level changes as never before. LiDAR (light detection and ranging) methods yield centimeter-scale (land-based) to meter-scale (airborne) measurements of topography and can “see through” vegetation, allowing analysis of hazards such as landslides and fault scarps that were not previously visible.

*Earth Science Literacy Principles* (Earth Science Literacy Initiative, 2009) and *Climate Literacy: Essential Principles of Climate Science* (Climate Literacy Network, 2009) present clear and complementary guidance on fundamental concepts students should know on Earth-related topics and will serve as a guide for achieving Objective 1 (Figure 2). The limited research into undergraduate Earth science conceptions demonstrate that students are not achieving competence on these principles (e.g., Libarkin, 2005; McCaffrey and Buhr, 2008). Geodesy falls within a subset of the specific literacy principles. Table 1 lists the Earth Science Big Ideas and Climate Literacy Principles that our curriculum will target. The two literacy principles overlap so we link them under five Themes. GECU modules will each address at least four of these themes.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Earth Science Big Idea (ESBI)</th>
<th>Climate Literacy Principle (CLP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Scientific inquiry/active research</strong></td>
<td>ESBI-1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.</td>
<td>CLP-5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling</td>
</tr>
<tr>
<td><strong>B. Complex systems</strong></td>
<td>ESBI-3. Earth is a complex system of interacting rock, water, air, and life</td>
<td>CLP-2. Climate is regulated by complex interactions among components of the Earth system</td>
</tr>
<tr>
<td><strong>C. Continuous change</strong></td>
<td>ESBI-4. Earth is continuously changing</td>
<td>CLP-4. Climate varies over space and time through both natural and man-made processes</td>
</tr>
<tr>
<td><strong>D. Water &amp; resources</strong></td>
<td>ESBI-5. Earth is the water planet ESBI-7. Humans depend on Earth for resources (including water)</td>
<td></td>
</tr>
<tr>
<td><strong>E. Human interactions</strong></td>
<td>ESBI-8. Natural hazards pose risks to humans ESBI-9. Humans significantly alter the Earth</td>
<td>CLP-7. Climate change will have consequences for Earth system and humans CLP-6. Human activities are impacting the climate system</td>
</tr>
</tbody>
</table>

*Ocean Literacy (NOAA et al., 2004) and Atmospheric Science Literacy (UCAR et al., 2007) principles may also be addressed by specific geodetic curriculum pieces. However, we focus on Earth Science and Climate for simplicity and tightness of fit to geodetic research topics.*

**3. Objectives & Outcomes**

The specific outcomes for GECU are a component of a broader vision for increasing the quantity and quality of undergraduate geodesy-related teaching and learning materials that will engage students in science with broad impact. The *UNAVCO Strategic Plan 2011-2015* (UNAVCO, 2011) and *A Foundation for Innovation: Grand Challenges in Geodesy* (UNAVCO, in press)
emphasize undergraduate geodesy education as a critical area for effort investment. This TUES Type 1 project will start this process promptly and on a sufficiently large scale to have immediate broad impact. We propose to develop, test, revise, and disseminate four comprehensive modules which feature geodetic data and methods in addressing real world geoscience challenges (Figure 2). Two modules will be for use at the introductory level and two for majors-level. In addition, recognizing that this will be a transformative but only initial step, we will write a curriculum developer’s manual. We envision this as a road map for sustaining the development of future curricula featuring geodesy. It will include steps for faculty to adapt cutting edge geodesy research to tractable components for use in undergraduate courses.

A. INPUTS

| NSF Funding | UNAVCO | TUES partner colleges, universities, and faculty | SERC | NAGT | Geodesy community | Earth science teaching community feedback |

B. OVERARCHING OBJECTIVES

1. Improve geoscience (particularly geodetic) knowledge base of undergraduate students both for general science literacy (introductory) and future science workforce (majors-level).
2. Improve effectiveness of teaching resources and pedagogy employed by faculty members teaching geodesy, geoscience, and allied sciences.

C. TUES TYPE 1 OUTPUTS

1. Development, testing, revision, and dissemination of four curricular modules featuring geodesy data investigations which support Earth science and quantitative literacy at both introductory and majors’ levels in diverse academic settings.
2. Developers’ manual to facilitate future integration of geodesy and other data into teaching materials.
3. Support for faculty in integrating curriculum into courses.

D. TUES TYPE 1 OUTCOMES

1. Students:
   a. Are able to apply authentic geodetic data and quantitative reasoning to addressing critical societal issues
   b. Have improved understanding of nature and methods of science
   c. Gain better understanding of relevant geoscience and climate literacies (Table 1) and the ability to apply them to critical resource, hazard, and environmental issues
2. Faculty:
   a. Adopt developed geodesy curriculum modules
   b. Include more connections between authentic data and addressing of critical societal issues
   c. Increase use of promising pedagogical practices in STEM education (e.g., Froyd, 2008)
   d. Use systematic assessment of student learning

E. LONG TERM OUTPUTS

1. Development, testing, revision, and publication of a larger collection of curricular modules featuring geodesy.
2. Support faculty in integrating curriculum into diverse institutions and course settings across the USA.

Figure 2. Logic model of GECU’s development vision including inputs, overarching objectives, TUES Type 1 outputs and outcomes (gray), and long term outcomes.

4. Current state of geodesy undergraduate teaching and learning resources

UNAVCO, with assistance from SERC, conducted an inventory earlier this year through web research, personal interviews, and an online faculty input questionnaire to determine the current state of geodesy teaching and learning materials. Identified resources fall under two categories: mention of geodesy in textbooks, and activities/resources available online.

Recent textbooks from a range of introductory Earth science courses – physical geology (Jordan and Grotzinger, 2011; Lutgens et al., 2010; Marshak, 2011; Murck, 2012; Reynolds et al., 2012), natural hazards (Abbott, 2011; Hyndman and Hyndman, 2010), and oceanography (Trujillo and Thurman, 2010) – generally make brief reference to geodetic techniques, most commonly mentioned is GPS for navigation, plate motion, and/or earthquake hazard studies. A few also mention GPS application to volcanic or landslide hazards. Only one, (Marshak, 2011) included examples of all of the above and mentioned geodesy’s importance to ice and climate studies.
Similarly, textbooks for relevant majors-level geoscience courses (geophysics, plate tectonics, structural geology, geomorphology, and cryosphere) range from not including the topic of geodesy to an in-depth chapter (Anderson and Anderson, 2010; Barry and Gan, 2011; Burbank and Anderson, 2012; Burger et al., 2006; Davis et al., 2012; Fossen, 2010; Fowler, 2004; Frisch et al., 2010; Gregory, 2010; Herring, 2009; Huggett, 2011; Kearey et al., 2009; Lockwood and Hazlett, 2010; Lowrie, 2007; Parfitt and Wilson, 2008; Pollard and Fletcher, 2005; Schmincke, 2005; Segall, 2010; Slaymaker and Kelly, 2007; Stacey and Davis, 2008; Turcotte and Schubert, 2002; Twiss and Moores, 2007). Most commonly, brief mention was made of the existence of GPS and sometimes other discipline-relevant techniques. Barry and Gan’s (2011) was the only book with significant mention of GRACE and other climate change geodesy. There are some texts completely devoted to geodesy; however, they are written at the level for researchers and graduate students (e.g., Dzurisin, 2007; Herring, 2009; Hwang et al., 2004; Meyer, 2010; Strang and Borre, 2012; Wahr, 1996). Our project may use them as technical references, but they would only be directly useful to the most advanced of undergraduate geodesy learners, not the general education student or typical geoscience major our curriculum will target.

Only one commercially published introductory laboratory manual (Busch et al., 2011) made any mention of geodetic subjects and that was a single figure and question regarding southern California GPS data. Other manuals we reviewed (Bursztyn, 2009; Jones and Jones, 2012; Knott, 2011; Ludman and Marshak, 2012; Ossian, 2010) omitted geodesy entirely, even in sections where it would have been a strong fit such as plate tectonics and volcanic hazard monitoring.

Many instructors who must compile their own classroom or laboratory exercises use resources posted on Earth science teaching websites from organizations such as UNAVCO, SERC, DLESE (Digital Library of Earth System Education), USGS (United States Geological Survey), NOAA (National Oceanic and Atmospheric Administration), and IRIS (Integrated Research Institutions for Seismology. Of these, only UNAVCO (http://www.unavco.org/edu_outreach/data/data.html) and SERC (http://serc.carleton.edu/NAGTWorkshops/geodesy/activities.html) have unique activities pertaining to undergraduate geodesy learning. UNAVCO has six activities (all related to GPS) appropriate for introductory undergraduate geoscience level. SERC has 18 activities contributed by the geoscience community on the Teaching Geodesy for the 21st Century site; about two-thirds are appropriate for majors-level and one-third for introductory courses. About half are related to GPS whereas gravity, volcanic hazards, LiDAR, and supporting skills or concepts have 1-3 activities each. DLESE, USGS, NOAA, and IRIS have some information, K-12 materials, and/or visualizations, but not undergraduate activities. Various faculty members such as Tom Herring (MIT), Eric Calais (Purdue), and Seth Stein (Northwestern) have posted useful geodesy-related (mostly GPS) lectures and activities and a number of faculty members have shared activities and course syllabi with UNAVCO E & O directly.

In total, the current state of geodesy teaching and learning materials for undergraduates includes abundant information (from too many different sources), many potential data sets, and the nuclei of many good ideas for activities (heavily weighted towards GPS). However, none of the resources include evidence of student learning efficacy and assessments are often weak. Activities are only implicitly tied to Earth science literacy concepts. Resources for classroom and activity-based learning are generally available separately, not paired in ways useful to other faculty. There are no geodesy activities on UNAVCO or SERC that pertain to the societally critical issues of water resources and climate change that geodetic observations are so effective at
addressing. In summary, there is great potential, but nothing well developed yet in the realm of geodesy undergraduate curriculum.

5. Geodesy community input

The geodesy community strongly supports the development of undergraduate geodesy curriculum. The need has been highlighted in the UNAVCO Strategic Plan (UNAVCO, 2011) and A Foundation for Innovation: Grand Challenges in Geodesy (UNAVCO, in press) but an effort of the scale of this proposal is not within the scope of UNAVCO’s standard facilities support. Well-attended breakout sessions were held at the EarthScope National Meeting (May 2011) and UNAVCO Science Workshop (March 2012) to solicit community input on requirements. A task force from the UNAVCO E&O Advisory Board held weekly conference calls through fall 2011 to refine ideas. This TUES Type 1 proposal is a critical step in pursuit of this goal, and builds on the work with SERC to develop and populate with existing resources the *Teaching Geodesy in the 21st Century* site. Input from the geodesy community and from SERC steered us towards a modular format (detailed below) with elements for both classroom and labs. There was strong support for developing both introductory and majors-level course materials. For majors, faculty favored modules that could be used separately in a variety of different courses or linked together in a course centered on geodesy or geophysics. Key collaborators have agreed to co-author, review or test material (see letters). Given the strong science community involvement, we are confident that faculty will be eager to use the curriculum when it is ready.

6. Project description

We propose to develop, test, revise, and disseminate four curricular modules that are (1) centered on issues of societal importance, to aid students in achieving Earth science and climate literacy, and (2) use geodetic data sets to develop quantitative reasoning skills. Each module will be tested by at least three institutions, at least one of which serves a major group underrepresented in science. Each module will contain an inquiry activity centered on geodesy data as well as classroom materials for two weeks of learning on the topic. In addition, we will produce a developer’s manual to aid future curriculum writing efforts to integrate geodetic data. The module development and testing is modeled on SERC’s InTeGrate STEP Center, allowing us to capitalize on the assessment instruments and expertise developed through that effort, which is also focused on geoscience learning in the context of societally important issues.

6.1 Research basis for instructional design

Many voices are calling for fundamental reform of undergraduate STEM education in the USA (NRC, 1999; PKAL, 2006 and the references therein). The engagement of all undergraduate students in STEM learning that features strong connections to society and the human condition lies at the center of this vision. To achieve this end, many recommend the increased use of inquiry-based teaching methods and scientific data to examine real problems and applications (e.g., Barstow and Geary, 2002; Bralower et al., 2008; PKAL, 2006). Using authentic data in the classroom supports content learning and increases students’ engagement in scientific inquiry, preparing them for solving real-world problems. As students analyze data, they gain perspective on its usefulness, validity, and limitations. The experience also improves quantitative reasoning. Inclusion of real data in undergraduate courses supports and enhances inquiry-based instruction. Inquiry-based instruction can vary from highly structured to quite open, but a strong consensus exists within the educational literature on the value of the approach (NRC, 2000, 2005).
The quantitative nature of geodetic data offers a rich opportunity to develop mathematics skills for both introductory and majors-level students. The geosciences include many very quantitative subdisciplines and it is essential for geoscience students to engage in this authentic component of Earth science study (Hancock and Manduca, 2005; Loudin, 2004; Manduca et al., 2008). However, many students come to geoscience courses with math phobia, requiring the use of proven models for supporting quantitative skill development. The Math You Need (http://serc.carleton.edu/mathyouneed/index.html) and Spreadsheets Across the Curriculum (http://serc.carleton.edu/introgeo/ssac/index.html) – both NSF CCLI/TUES Type 1 & 2 funded – provide online tutorials to be used in parallel with introductory geoscience courses to increase quantitative literacy and student engagement (Vacher, 2005; Wenner et al., 2009, 2012). At the majors’ level, successful strategies have also been established (Hancock and Manduca, 2005; Manduca et al., 2008) (http://serc.carleton.edu/quantskills/index.html). A number of promising practices for promoting undergraduate learning are emerging (Froyd, 2008 & references therein). Two practices, small group work and engaging activities, received the highest rating for student learning effectiveness and ease of implementation; thus GECU will certainly use them.

So in total, the body of research on STEM undergraduate education points us towards including all students, situating science learning within a societal context, using inquiry-based instruction with real data, developing quantitative skills, and having students working in small groups on engaging activities. Geodesy is ideally suited to this model because it addresses natural hazards, climate change, and water resource management, all highly relevant to society. Geodesy encompasses all aspects of STEM. The science straddles the fields of geoscience and physics while including elements of technology and engineering. Working directly with the data not only engages students in the actual inquiry science processes, but naturally requires development of quantitative math skills.

6.2 Curricular module topics
Our long-term vision is to have a large suite of modules for both introductory and majors-level; this TUES Type 1 project will focus on establishing, refining, and improving the development process while completing four modules total (at least two at each level). Table 2 highlights the types of topics the modules will address. Final topics will be decided at the start of the project to dovetail with other curriculum development efforts that may have advanced by then (e.g., SERC’s InTeGrate project and NSF TUES Type 1 proposal by Wang*; Univ. of Houston).

*Wang’s proposal to develop a geodesy course is in submission to TUES too and is a complementary, not overlapping, endeavor.

Table 2. Example module topics, relevant data sets, appropriate courses, and associated literacy themes (Table 1). Final selection of topics for development in TUES Type 1 will be determined at project start.

<table>
<thead>
<tr>
<th>Overarching societal issue Relv. data sets</th>
<th>Introductory [appropriate courses] Literacy principles</th>
<th>Majors level [appropriate courses] Literacy principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate tectonics &amp; earthquake hazard GPS, InSAR, LiDAR</td>
<td>How big could the earthquake be?: Investigation of plate motion from GPS data to determine potential rupture in next “big one” supports learning about plate tectonics, earthquakes, and hazards. [Intro Environmental Geol./Sci., Intro Physical Geol., Intro Natural Haz.] Inquiry, Systems, Change, Humans</td>
<td>Assessing regional earthquake hazard: Compare present day GPS strain fields with long term geologic slip rates to calculate orientation and displacement of mismatch and support learning of plate boundaries and seismic hazard. [Geodesy, Geophysics, Tectonics, Structural Geol.] Inquiry, Systems, Change, Humans</td>
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</table>
### Curricular module components

Each module will contain materials needed for two weeks of a course and will be anchored by an inquiry investigation using geodesy data. In order to maximize flexibility for different institution and course needs, each module will be designed to stand alone but also be useable in a sequence. Furthermore, a faculty member could choose to use just a single component of the module—for example the primary activity—and not include all the supporting materials intended for classroom time or homework. Although there will be some variability between modules, overall coherent and consistent standards for structure will support ease of adoption.

The modules will include curricular materials that are familiar to faculty and easy to implement, in ways informed by current research on STEM education best practices. PowerPoint slides will be accompanied by in-class small group exercises and thought problems such as think-pair-share. Most introductory Earth science classes are still scheduled as classroom and laboratory sessions and thus trying to force a paradigm of removing boundaries between class and lab (e.g., Duch et al., 2001; Herreid, 2004; Wood, 2009) would be premature. However, an increasing number of geoscience faculty members have participated in Cutting Edge or similar professional development workshops and have started to adopt alternative teaching and learning formats that include engaging students in active learning, even during “lectures”. Versatile, well tested, and well explained activities that feature effective teaching strategies that can still be implemented in a traditional setting, will contribute to a paradigm shift in undergraduate STEM education.

Anticipated GECU module components include:

- **Teaching notes** (Intended audience, appropriate courses, expected prior knowledge, student learning outcomes, relevant literacy principles, module rationale, background content information, instructional strategy information, common pitfalls and misconceptions)

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| Climate change | Coastal cities and sea level rise: Investigation of ice loss (GRACE) and sea level (ocean altimetry) to make urban action recommendations supports climate change and water cycle learning, [Intro Envir. Geol./Sci., Intro Physical Geol., Intro Geography, Intro Oceanography, Intro Natural Haz.] Inquiry, Systems, Change, Humans | Greenland ice loss and isostatic rebound: Analysis of ice mass (GRACE, ICESat), ice flow (InSAR), and uplifting GPS stations to determine ice loss rates and crustal response supports learning about cryospheric change, crustal properties, and geodetic data analysis. [Geophysics, Geodesy, Cryosphere, Climatology] Inquiry, Systems, Change, Humans |
| Water resources | Will we have enough water?: GRACE data investigation into mass loss in several critical aquifers (ex. CA Central Valley) supports learning about water cycle and water resources. [Intro Physical Geol., Intro Envir. Geol./Sci., Intro Geography] Inquiry, Systems, Water, Humans | Monitoring wetland surface flow: InSAR and gauge data investigation of protected wetland near large urban development supports learning about InSAR methods, environmental monitoring, and water cycle. [Geophysics, Geodesy, Hydrogeol., Envir. Geol.] Inquiry, Systems, Water, Humans |
| Landslide hazards | Slip sliding away: LiDAR documentation of sliding apartment complex shows slope failure due to over steepening and supports surface processes and land use learning. [Intro Physical Geol., Intro Envir. Geol./Sci., Intro Geography, Intro Natural Haz.] Inquiry, Systems, Change, Humans | Will the land-fill need to be moved?: Through InSAR, GPS, and LiDAR analysis students determine creep slip rates below a landfill and make policy recommendations. [Geophysics, Geodesy, Envir. Geology, Geomorphology] Inquiry, Systems, Change, Humans |

GPS = Global Positioning System; GRACE = Gravity Recovery and Climate Experiment; ICESat = Ice, Cloud, and land Elevation Satellite; InSAR = Interferometric Synthetic Aperture Radar, LiDAR = Light Detection and Ranging

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Anticipated GECU module components include:

- **Teaching notes** (Intended audience, appropriate courses, expected prior knowledge, student learning outcomes, relevant literacy principles, module rationale, background content information, instructional strategy information, common pitfalls and misconceptions)
- Assessments (Embedded formative and summative [see Module Assessment section below])
- Classroom materials (PowerPoint slides, in-class small group activities)
- Student preparation materials (Topic-specific readings, homework assignments)
- Lab/Activity (Teaching instructions, student instructions, data sets)

**Assessments:** All modules will meet the standards defined by the InTeGrate Step Center Design rubric which incorporates broad goals of the project and researched guidelines for best practices in curricular development. Use of the rubric is designed to ensure that all reviewed modules will eventually meet expectations through a continuous quality improvement process. The structure promotes a backwards design (Wiggins, 2005) approach in which the module authors first consider what big ideas, processes, 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 advance levels and opportunities for reflection and synthesis are supported through the use of the rubric.

**Student preparation materials** will include additional readings needed to support geodesy-specific learning not commonly available in texts. Homework will often pertain to the quantitative skills needed for the larger activity. For example in an introductory course, students might do a *Math You Need* module on interpreting trend lines or complete a spreadsheet tutorial. In the major’s level students might download data and do some practice computational exercises or do a tutorial designed to help them use and apply learned mathematical principles to geoscience problems.

The strength of geodesy data products is their ready accessibility for manipulation, evaluation, and interpretation. Some are easy to access online from established portals. Others will need to be distributed with the curriculum materials in formats that support student manipulation and interpretation. Open formats, archives, and web sites for data products obviate proprietary issues that sometimes hamper acquisition of underlying data. All EarthScope data and much global GPS data and results are available through UNAVCO, the IGS (International GNSS Service) CDDIS archive, and SOPAC at Scripps. LiDAR data in point clouds or Google Earth format (.kmz) shaded relief images are available through OpenTopography. GRACE and other NASA satellite data are available through the project websites. InSAR products from around the world are available from the science community. The major hurdle in including geodesy data will be data portals and formats intended for highly knowledgeable researchers, not educators or students; but the geodesy science community is eager to support this endeavor and brings a wealth of knowledge about existing products that adapt to specific topics and exercises.

UNAVCO E&O has extensive experience with GPS data use for educational purposes and has a project slated to start in summer 2012 to develop educator metadata sheets and improve educator oriented access for Plate Boundary Observatory (PBO) GPS products. This situation is not unique to geodesy and guidelines exist for creating metadata files and access portals oriented to educators (Ledley et al., 2008; Manduca and Mogk, 2002). We intend to use GECU as a forum for testing and encouraging broader geodesy data accessibility for educational use.

**6.4 Module assessment**

GECU will capitalize on the InTeGrate STEP Center model for development and testing of materials. Ellen Iverson, SERC’s Director of Evaluation, will lead assessment and evaluation. In addition, a member of the InTeGrate Assessment Team, a group of 10 geoscientists and educators selected for their expertise in educational research and evaluation, will be assigned to consult with our teams as they develop the modules. The consultant will help us to meet the
standards of the InTeGrate Design Rubric, which encodes research-based principles for effective instruction. The consultant will also assist with embedding assessments within the materials that demonstrate when learning related to the module objectives is complete. These assessments will be used by all faculty members testing the curriculum and are required work that contributes to the student’s course grade.

Once the materials are completed and meet the standards of the Design Rubric, they will be tested in three classrooms representing a spectrum of educational environments from PI and collaborating institutions (see letters). At least one (and likely more) will contain significant populations underrepresented in science (ex. minority, urban and rural poor, and Native American). The project will collect student data from the embedded assessments as well as appropriate pre-post data drawn from the Geoscience Literacy Exam, which InTeGrate will pilot in fall 2012. The assessment will address systems thinking, interdisciplinary problem solving, career interest, motivation, student engagement, and geoscience literacy (Climate Literacy Network, 2009; Earth Science Literacy Initiative, 2009; NOAA et al., 2004; UCAR et al., 2007). Student demographic data will be collected but names will not be retained. Faculty will complete a structured reflection form to provide course context, feedback on curriculum implementation process, and additional insights that might inform interpretation of variability in student learning gains. Data will be collected as materials are piloted and submitted using a system coordinated through the SERC website. Iverson will analyze the student assessment data for learning gains and also look for patterns and trends in student learning gains across demographic groups and institutional type. After the materials are piloted in the classroom, this analysis will be used to refine the materials before they are published on the project website. The InTeGrate data from the Geoscience Literacy Exam will be used to situate the results from this project.

6.5 Developer’s manual

The long term vision is to develop five to eight modules each for introductory and upper division courses. As an NSF facility, UNAVCO tailors individual projects to establish scalable infrastructure and workflow. In order to support and coordinate broader community curriculum development efforts, successful methodology and lessons learned from this project will form the basis for a developers’ manual that highlights the steps, pitfalls, and solutions encountered in moving from cutting edge geodesy research to high quality undergraduate curriculum. It will include formative and summative assessment strategies and case studies from module authors and testers to showcase a range of implementation strategies. The manual will be published on the SERC and UNAVCO websites, featured in dissemination webinars, and possibly highlighted in a science news article (see below, Dissemination). We anticipate the manual to be of value for any scientist interested in integrating data-rich investigations into undergraduate courses.

6.6 Project team and institutions

The project partners bring together a strong suite of experience in curriculum development, undergraduate instruction, student learning assessment, online curriculum publication, and geodetic knowledge. The primary collaborators are UNAVCO (geodetic research consortium), Mt San Antonio College (large urban community college with diverse student body), and Indiana University (research-oriented university). Additional breadth in institution type and geodetic science knowledge will be contributed by authoring, testing, and advising collaborators (see letters). SERC and its InTeGrate project will provide student learning assessment, independent program evaluation, a high-visibility online publishing venue, and a host site for webinars.
UNAVCO, a non-profit university-governed consortium of 103 U.S. academic organizations, operates NSF’s national geodetic facility and facilitates innovative academic research around the world; it has >350 active faculty participants at USA institutions. UNAVCO E&O systematically focuses on providing infrastructure for geoscience and geodesy learning and has extensive experience engaging teachers, K-20 students, university faculty, and researchers. Projects include the RESESS (Research Experiences in Solid Earth Sciences for Students), an undergraduate summer internship program dedicated to increasing the diversity of students entering the geosciences. UNAVCO efforts will be led by Dr. Beth Pratt-Sitaula (CoPI) and overseen by President, Dr. Meghan Miller (PI). Miller was a faculty member and dean for 18 years at Central Washington University (a regional comprehensive university and founding member of UNAVCO) and oversaw the revitalization of a geology majors’ program that grew from 8 to 75 students over four years and integrated geodesy, field work, and student research across lower and upper division courses. Miller actively participated in the national community that advanced innovative learning strategies (such as Project Kaleidoscope), and led successful NSF proposals that integrate technology into the undergraduate curriculum. As president of UNAVCO since 2008, she focuses initiatives and advances goals of the academic geodesy research community, her principal role in this project. Pratt-Sitaula brings geoscience, educational, and logistical expertise to the project. She led UNAVCO’s inventory of existing undergraduate geodesy curriculum. 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. She served as a PI, instructor, and assessment lead on the EarthScope education project Teachers on the Leading Edge (http://orgs.up.edu/totle/) (Pratt-Sitaula et al., in review). She helped install a GPS network in Nepal (Pratt-Sitaula et al., 2009) and is a CoPI on an NSF-MRI proposal which purchased a terrestrial LiDAR scanner (TLS) for student and faculty use.

Rebecca Walker (PI) is a professor in the Department of Earth Sciences and Astronomy at Mount San Antonio College (MtSAC), a community college with over 40,000 credit students. With a significant percentage of students from underrepresented groups in STEM (2008-2009: 43.8% Hispanic; 26% Asian-Pacific Islander; 16.8% Caucasian; 5.7% Black; 1.8% Non-White; 0.5% Native American/Alaskan; 5.4% n.d.) and over 40 sections of introductory level geology, oceanography, and meteorology courses offered per semester, MtSAC is an excellent institution for implementing the curriculum at the introductory level where it will reach both STEM and non-STEM majors. Walker teaches a variety of courses suitable for implementation of a geodesy curriculum, including physical geology, field studies, oceanography, natural disasters, geology of California, and Earth science (for K-12 pre-service teachers). She was selected as a co-author for the SERC InTeGrate climate change module team to be completed August 2012 and tested in the fall. Her experience with InTeGrate will provide valuable knowledge within the PI team of the development and assessment process in that program and facilitate working with SERC efficiently. From 2005-2006 she worked as an Education Specialist at UNAVCO, where she developed geodesy curricular materials and teacher/faculty workshops involving the use of EarthScope data in K-12 and college classrooms. As a PI on a Hewlett Foundation-funded Faculty Inquiry Network grant from 2009-2011, she and collaborators adopted new instructional materials and teaching strategies to promote self-directed learning and metacognition for introductory students on field trips.

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 Dept.’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 imbedded assessment. A major component of the recent field camp curriculum development was a week-long 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 E & O. They have committed to co-authoring, testing, or reviewing for content accuracy as needed. IU has at least three introductory (Earth science, earthquakes and volcanoes, and environmental geology) and two majors-level courses (structural geology and applied geophysics) that would use modules developed by this TUES project.

SERC has extensive experience in geoscience education program evaluation, assessment of student learning, and online teaching resource publication. Ellen Iverson (SERC’s Director of Evaluation and primary project liaison) has been evaluator for 25 science education projects and oversees assessment of student learning for SERC’s InTeGrate STEP Center. The SERC web content management system is specifically designed to allow faculty across the country to work collaboratively on materials development and to produce an integrated and functional website from these distributed efforts. It includes private workspaces supporting project management, a full development site for creating site content prior to testing and publication, and data collection tools that support testing and evaluation of materials. SERC’s website hosts thousands of teaching and learning resources, receiving over 11,000 visitors per day. SERC has extensive experience hosting webinars. (SERC letter and facilities and Iverson bio are in Suppl.)

6.7 Work plan & timeline

Pratt-Sitaula (UNAVCO), Walker (MtSAC), and Douglas (IU) will be the project’s core development team (Figure 3). SERC will provide student assessment, online publishing technology, and independent program evaluation. Walker will be primarily responsible for authorship, testing, and revision of introductory modules; whereas Douglas will lead majors’ level modules. Pratt-Sitaula will serve as the logistical and communication hub, provide data sets and supporting materials to authors, coordinate with SERC and NAGT, write the geodesy curriculum developer’s manual, and lead dissemination. Miller will be responsible for coordination with the science community and the successful accomplishment of the work. UNAVCO will provide administrative and technical support.

The project will contain two cycles of module development, testing, and revision with an introductory and majors-level module produced in each cycle for a total of four modules in all. In order to broaden community participation, teaching approach, institution type, and content expertise, Walker and Douglas will each work with a co-author drawn from interested collaborators. GECU will start in January 2013 with module template design, module topic selection, curricular inventory mining, co-author and content advisor identification, and data set acquisition (Table 3). The entire development and assessment team will meet at UNAVCO’s
Boulder headquarters in May (Pratt-Sitaula, Walker, Douglas, two co-authors, UNAVCO scientists, Iverson, and InTeGrate assessment consultant). Pratt-Sitaula will work with each authorship team to ensure they have the needed supporting materials such as prototype curricula drawn from the existing inventory, supporting-skills modules such as Math You Need, and geodetic data sets. Module development will be done over the remaining spring and summer, with email and virtual conferencing as needed for authorship teams (PI, co-author, assessment person, and content advisor) and the entire group. A timeline with checkpoints for specific deliverables will be adhered to (similar to the one in use by InTeGrate).

Each module will be tested the following academic year by both authors and a 3rd faculty member from a different type of institution (often minority serving). Ideally this “tester” faculty member will also represent a different sphere of geoscience teaching background—for instance someone not particularly versed in geodesy, to help ensure the modules are useable to a broad range of educators. For instance, we have tribal college and comprehensive university faculty willing to test as needed (see letters). Stipends will be provided for co-authors, testers, and advisors upon completion of work. PIs and other available team members will meet at a national meeting during the academic year to discuss module testing and revision. SERC will process student assessment results and faculty feedback surveys and provide the team with suggestions for improvement. Walker and Douglas will lead revision efforts with review and input from their co-authors over the following summer. The final modules will be published in

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<th>Table 3. Project timeline.</th>
<th>Year 1 (2013)</th>
<th>Year 2 (2014)</th>
<th>Year 3 (15)</th>
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<tr>
<td>Module design &amp; development</td>
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<tr>
<td>Prep (Module template design, topic selection, curricular inventory mining, co-author identification, data set acquisition)</td>
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<td>Module development (incl. imbedded assessments by SERC)</td>
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<td>Content consulting &amp; review</td>
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<td>Module revision, final review, and publishing</td>
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<tr>
<td>Evaluation &amp; assessment</td>
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<td>Classroom testing for student learning/faculty feedback (SERC)</td>
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<td>Final evaluation report from SERC</td>
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<td>Dissemination &amp; Sustainability</td>
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<tr>
<td>UNAVCO Science workshop</td>
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<td>NAGT webinars and meeting presentations</td>
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<td>Developers manual written and revised</td>
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<tr>
<td>News article (EOS, Earth, or In the Trenches)</td>
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<td>Final SERC collection publication</td>
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<td>First module development cycle</td>
<td>Second module development cycle</td>
<td>Related to whole-program</td>
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late summer 2014 (16 months after initiation) after Pratt-Sitaula has completed final editorial review to ensure consistency and adherence to agreed format and style.

The entire process will be repeated spring 2014-summer 2015 with different co-authors and testers to aid in wider community involvement. In 2014, Pratt-Sitaula will start dissemination efforts (see below Dissemination) and writing the developer’s manual (see above Developer’s Manual). SERC will provide the final program evaluation report in summer 2015. Although different teams will do introductory and majors-level modules, regular communication and review of each other’s material will ensure that efforts are complementary and informed by mutual needs. We have very intentionally chosen a team and development model aimed at promoting and maintaining communication between different curricular levels and institution types (community college and research university) while building STEM education community.

6.8 Dissemination

Dissemination of modules and developers manual will occur via webinar series, workshops, conference talks, science news article, and SERC’s website (linked to UNAVCO and NAGT). To publicize the project and gain more community input, project PIs will attend the spring 2014 UNAVCO Science Workshop to give a talk and run a breakout session to engage the geodesy community. Each PI will attend his/her regional NAGT meeting and give talks about GECU to better reach community colleges and primarily undergraduate institution faculty. Cutting Edge, InTeGrate, and NAGT professional development workshops will feature GECU as appropriate.

In order to bring together a range of instructors and researchers from different types of institutions, we will sponsor (in collaboration with NAGT) a five-part webinar series in spring 2015. We see this as critical for both dissemination and STEM education community building. The theme of the webinars will be using data investigations to support geoscience learning and they will be patterned after the NAGT-sponsored Spatial Thinking Journal Club. Prior to the webinar, participants will review the designated module or the developer’s manual and post questions/comments. The webinars will be led by the module authors (instructional expertise) and a research scientist (content expertise). We envision the resulting conversation as an excellent forum for aiding would-be users to gain both the pedagogical and content background needed to successfully implement the modules or develop their own future curricula, as well as provide a network of people to turn to for advice. We expect to attract >30 participants in all.

At the conclusion of the project, we will write a news article in a high-profile venue such as EOS, Earth magazine, or In the Trenches to publicize the collection and report findings on the geodesy data integration process. The combined traffic to SERC sites was nearly 4 million visitors last year (Manduca, pers. comm., 2012) so publication on the site ensures rapid, widespread dissemination. Besides being housed in a geodesy-specific collection, the modules produced in this project will be incorporated into the Teach the Earth, InTeGrate, Cutting Edge, Quantitative Skills, and Using Data sites as appropriate.

7. Project evaluation

Iverson will also serve as the independent program evaluator to determine whether the project as a whole has succeeded in achieving its stated outcomes (Figure 2). The summative evaluation for the project will assess the impact of the curricular modules on student learning and faculty teaching practices. To evaluate the effect of the modules on student learning and to assess the quality of the implementation, materials rubric scores and the aggregate student learning gains for embedded assessments will be used as quantitative measures. Patterns and trends in student
learning gains for both the embedded assessment and the pre- and post-instruction Geoscience Literacy Exam scores will be analyzed, asking whether learning gains are evenly distributed across demographic groups and institution types. Structured faculty reflection forms from the classroom pilot faculty will serve as qualitative cases for the use of materials in different contexts. Iverson will determine the project’s ultimate reach by evaluating the effectiveness of gaining faculty participation as module authors, module testers, and dissemination webinar participants, and calculating the numbers of resource users identified by web analytics.

8. Sustainability and STEM education community building

Both the sustainability and the STEM education community building of this project will be anchored in the experience and longevity of UNAVCO, SERC, and NAGT. UNAVCO E&O is a permanent program of UNAVCO and accesses a community of geodesy educators ready to implement and sustain the effort alongside a strong research connection to keep the science up to date. UNAVCO is committed to maintaining currency of materials produced by this TUES Type 1 and will dedicate 40 hours of educational staff time biannually to updating curriculum data sets, text, and web links. This is in addition to continuing to promote this curriculum and further module development. SERC web materials are guaranteed a life of at least 10 years. Both the InTeGrate Program and NAGT are actively researching ways of sustaining and updating materials and our partnership with them will ensure we are able to learn from their experience.

The curriculum produced by this project will conform to recommendations on how best to transform undergraduate STEM learning (grounded in societally important issues and literacy principles; inquiry-based investigations that use authentic data, technology, and quantitative reasoning; etc.). Modules will be tested at a variety of different institutions with students from across the spectrum of groups represented and under-represented in STEM and faculty both well-versed and only slightly familiar with geodesy. Thus, the collection will be of high value to any geoscience instructor, whether or not geodesy is of particular importance to them. Within the geodesy community, the strong commitment and need for this curriculum will ensure that many faculty members use it, beyond just the people immediately involved in the development.

9. Results from prior NSF support

OEDG-0914704, Track 2: Research and Education in Solid Earth Science for Students (RESESS): Developing a Sustainable RESESS Program, $1,179,864, 9/15/2009 to 8/31/2014. PI: M. Meghan Miller and others. The RESESS internship program pairs minority undergraduate students with geoscience researchers (e.g., Sloan et al., 2011). The 2012 applicant pool was the largest, most diverse, and most academically qualified one to date with 17 interns selected from 130 applicants. Since 2005, RESESS has sponsored 37 student interns. Of those, 21 are still undergraduates, 16 have bachelors’ degrees, two are working as geoscience professionals and 12 are in graduate school (10 in the geosciences).

EAR-0745526, Collaborative Research: Teachers on the Leading Edge: Linking K-12 Earth Science Teachers to EarthScope, $162,650, 2/15/08 – 1/31/12. PI: B. Pratt-Sitaula. Introduced 105 K-12 Earth science teachers to EarthScope science (including geodesy) and Cascadia geologic hazards. It proved successful at increasing teacher confidence and content knowledge and leading to high rates of curricular implementation. Subsequent dissemination by program participants has reached >30,000 K-12 students and >1500 other adults (teachers, administrators, etc.). Project findings have been published in journal articles (Butler et al., 2011; Groom et al., 2011; Pratt-Sitaula et al., in review) and more than 18 abstracts at national meetings.
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