Using Remote Sensing and Geospatial Technology for Climate Change Education

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ABSTRACT

This curriculum and instruction paper describes initial implementation and evaluation of remote-sensing exercises designed to promote post-secondary climate literacy in the geosciences. Tutorials developed by the first author engaged students in the analysis of climate change data obtained from NASA satellite missions, including the LANDSAT, MODIS, ASTER, SSMIS, AIRS and GRACE instruments. The tutorials incorporated image processing technology through software such as ESRI's ArcGIS and ERDAS Imagine. The relative emphasis on the technological tools versus the application to improving knowledge about climate change was adjusted across implementation in three geography courses. The adjustment of the relative emphasis placed on four primary teaching and learning objectives provides a framework for considering adaptation of the exercises across the educational spectrum. For example, activities are already being designed to expand to secondary school and general elective undergraduate geography courses. Online material provides full details for implementation of each exercise and associated student-generated products. Pre- and post-course surveys provided student perspectives about the courses and their learning. Student performance on completion of the tutorials was monitored by the instructor and performance on independent course projects evaluated students' ability to learn and apply their knowledge and skills to problems of their choice. Survey and performance data illustrated that the tutorials were successful in meeting their intended learning objectives. Discussion highlights the unique opportunities these tutorials provided to engage introductory and advanced students in authentic and relevant analysis of satellite data to explore climate change. *© 2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-040.1]

Key Words: satellite remote sensing, geospatial technology, GIS, climate change

INTRODUCTION

Under a NASA grant, *Mathematical and Geospatial Pathways to Climate Change Education*, students at California State University, Northridge (CSUN) integrated Geographic Information Systems (GIS), remote sensing, and satellite data technologies to the study of global climate change. ESRI's ArcGIS and ERDAS Imagine mapping, spatial analysis and image processing software were used to explore NASA satellite data to examine the Earth's atmosphere, hydrosphere and biosphere in areas that are affected by climate change or affect climate. These technology tools were incorporated into climate change and remote sensing courses in the Geography Department to enhance students' knowledge and understanding of climate change through hands-on application of image processing techniques to NASA data. Several sets of exercises were developed with specific learning objectives in mind. These were: (1) Students will be able to select and utilize the most appropriate satellite for addressing environmental questions; (2) Students will become proficient in locating, downloading, and importing remotely sensed data; (3) Students will generate and utilize indices to quantify environmental indicators through the use of image processing software; (4) Students will utilize and interpret remote sensing imagery in relation to core climate change concepts.

This article describes the exercises developed, and their application in CSUN geography classes. Exercises were implemented in three different geography classes—advanced undergraduate Global Warming, undergraduate Remote Sensing, and a graduate seminar in Remote Sensing. The exercises developed for each course differed in the relative emphasis on the learning objectives above. For example, while both remote sensing classes emphasized mastery of objective 1, development of objectives 2 and 3 with emphasis on the technology and analysis, the graduate seminar emphasized the application of methods to student-generated questions (objective 4), many of which were relevant to climate change. The focus of the global warming class was to teach climate science, evidence for warming, future climate projections, and mitigation, which involved mastery of objective 4 but only awareness of objectives 1 and 2. Thus, exercises in the Global Warming class were less focused on methods and more on the applications to knowledge of climate change processes.

Initial assessment of student knowledge, attitudes, and behaviors associated with these activities, particularly about climate change, was measured. Pre- and post-course surveys revealed student perspectives about the courses and their learning about remote sensing and climate change concepts. Student performance on the tutorials and course projects evaluated students' ability to learn and apply their knowledge about climate change and skills with remote sensing to assigned problems or proposed projects of their choice. Survey and performance data illustrated that the exercises were successful in meeting their intended learning objectives. Discussion highlights the unique opportunities these

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tutorials provided to engage introductory and advanced students in relevant analysis of Earth systems using satellite data.

Remote Sensing of the Earth, Ocean, and Atmosphere

Radiation is emitted from the sun over the full electromagnetic spectrum but primarily in the range of wavelengths from ultraviolet to infrared. Humans only see a small part of the spectrum—the visible spectrum (wavelengths between blue and red light). Satellite instruments have been designed to detect a larger part of the spectrum including ultraviolet and shortwave infrared energy reflected by Earth's surface or scattered by the atmosphere, and to record the energy emitted by the Earth itself, which cannot be seen by the human eye. NASA has launched many satellite instruments to monitor global environmental change in the Earth and atmosphere over the past four decades. These include the Landsat series beginning in 1972 (NASA Landsat, 2013), the Terra and Aqua satellites carrying the MODIS (NASA MODIS, 2013), ASTER (NASA ASTER, 2013) and AIRS (NASA AIRS, 2013) instruments, the SSMIS instrument (NSIDC, 2010) aboard the Defense Meteorological Satellite Program (DMSP) satellites, and the two GRACE spacecraft (NASA GRACE, 2013) launched in 2002. Data from these satellite missions are included in the tutorials developed to date.

Satellite data are available in a range of levels from 0 to 4. Low level data are unprocessed raw data, whereas higher level data have been processed and formatted into finished products (NASA Earth Science, 2013). The level of data one chooses to work with will depend on the application. For example, composite global cloud-free maps of land cover derived from multiple instruments would be available as a Level 4 product, whereas recorded light intensity reflected off the Earth's surface in each individual band (wavelength range) would be a Level 1 product. The tutorials emphasized the processing of Level 1, 2 and 3 products, thereby helping students understand the differences in these products and how higher level products are generated from lower level ones. In some cases students were asked to reproduce higher-level NASA products. This was done so that students could gain confidence in their image processing skills before advancing to future unguided investigations.

Connections to Global Climate Change Education and the Practices of Science

Satellite remote sensing data are ideal material for incorporation into all levels of geoscience coursework to promote the study of the Earth, its oceans, and atmosphere. The focus here is on how remote sensing data engaged students in the study of global climate change. Although this coursework was tailored to undergraduates and graduates it provides a possible framework for teaching climate change at the middle and high school levels under the new Next Generation Science Standards (NGSS) which focus on this content as a core discipline (Achieve, 2013). These standards specify performance expectations for students expressed as engagement in key organizing disciplinary concepts (like global climate change) within the context of science inquiry and engineering design practices (asking questions, analyzing data, etc.). While not designed explicitly around the NGSS, the proposed remote sensing tutorials incorporate many of the Earth Science content and scientific practices emphasized in the standards.

The understanding of how people learn (Bransford et al., 2000) indicates that explicit attention to prior knowledge, especially misconceptions and their correction, is a core principle of effective learning. The science behind global climate change is complex and subject to misconceptions, particularly in the United States. Although an increasing proportion of the public now believe there is solid evidence for warming only 42% believe that warming is mostly caused by human activity (Pew Research Center, 2012). The developed tutorials allow students to process and analyze satellite data and draw conclusions about global climate change for themselves. By having students process real satellite data and analyze resulting images, they can discover the reality behind the complex science of climate change and be more informed about the potential impact of and on human civilization.

Description of Tutorials

For each tutorial, a brief introduction serves to describe the key global climate change content connections. Table I provides an overview of learning objectives for each conceptual part of the tutorial as well as technology tools and software requirements. The choice of satellites and processing techniques were made so that students would be exposed to the array of instruments and the tools most commonly applied to study climate change and its effects. While many of the exercises could have employed data from the same instrument, the use of data sets from a variety of instruments enables students to understand differences between the instruments and therefore positions the students to make informed choices when making a selection for future studies. These tutorials were designed to provide students with basic skills that they could employ in their final projects. In the case of the tutorial employed in the climate change course, it provided guided instruction in GIS and in computation of carbon sequestration by forests. In the other tutorials, students learned how to access and process satellite data to acquire information on climate change-related phenomena. This knowledge and skills puts them in good stead for their course-related projects and future independent investigations. The tutorials are publically available for download, with accompanying data (or instructions for its access) from our website (CSUN, 2013).

Tutorial 1: Mapping snow cover using MODIS data

Snow cover is an important component of the climate system and an indicator of climate change. Its presence or absence is indicative of winter temperatures and can be used to monitor climate change when mapped over many years; it also has an important feedback on climate in that it is a good reflector of sunlight and thereby helps to keep the Earth cool by preventing absorption of sunlight (Budyko, 1969). In a warming world snow cover decreases and thus further warming ensues as more sunlight is absorbed (so-called albedo feedback effect). Snow is vitally important for its role in providing freshwater storage for much of the world's population (Barnett et al., 2005).

In this exercise students learn how to generate a snow cover map for a single day from individual bands of MODIS reflectance data (Level 2) using Yosemite National Park in the Sierra Nevada mountain range and a day in January 2011

TABLE I: Alignment of course materials and exercises with learning objectives (A: Awareness, D: Development and M: Mastery).

	Satellite Instrument	Software Required	(1) Students Will Be Able to Select and Utilize the Most Appropriate Satellite for Addressing Environmental Questions.	(2) Students Will Become Proficient in Locating, Downloading, and Importing Remotely Sensed Data.	(3) Students Will Generate and Utilize Indices to Quantify Environmental Indicators Through the Use of Image Processing Software.	(4) Students Will Utilize and Interpret Remote Sensing Imagery in Relation to Core Climate Change Concepts.
Geog 416: Global Warming (21 students enrolled)						
Using Landsat to Examine Deforestation in Brazil	Landsat	ArcMap	A	A	D	M
A Plan for Replacing Fossil Fuels in the U.S. with Renewable Energy Sources		ArcMap				A
Geog 407: Remote Sensing and Lab. (22 students enrolled)						
Using MODIS to Analyze the Seasonal Growing Cycle of Crops	MODIS	ArcMap (optional), ERDAS Imagine	M	D	D	A
Fire Mapping Using ASTER	ASTER	ArcMap, ERDAS Imagine	M	D	D	D
Student Satellite Presentations	Any		M			A
Geog 690D: Graduate Seminar in Remote Sensing (Spring 2012: 17 students; Spring 2013: 14 students)						
Mapping Snow Cover Using MODIS	MODIS	ArcMap (optional), ERDAS Imagine	M	M	D	M
Mapping Sea Ice Using a Microwave Imager/Sounder (SSMIS)	SSMIS	ArcMap (optional), ERDAS Imagine	M	M	D	M
Using GRACE to Evaluate Change in Greenland's Ice Sheet	GRACE	ArcMap	M	M		M
Mapping Global Temperature, Carbon Dioxide and Ozone Concentrations Using AIRS	AIRS	ArcMap	M	M		M
Student Project	Any	ArcMap or ERDAS Imagine	M	M	M	M

as an example (Fig. 1). They verify their map by comparing it to a snow cover map generated by NASA (Level 3 product). The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on Terra and Aqua satellites is part of NASA's Earth Observing System (EOS) established for long term observations of the Earth. Although the authors apply the snow cover study to the Sierra Nevada mountains, the same methodology can be applied to any geographical area worldwide. Snow has a high reflectance in MODIS band 4 (0.55 μm, green) and a low reflectance in band 6 (1.64 μm, near infrared). The Normalized Difference Snow Index (NDSI), defined as the difference in reflectances of these two bands divided by their sum, or (band 4 − band 6)/(band 4 + band 6), takes advantage of these characteristics to distinguish snow from features with similar appearance such as clouds (Hall et al., 2002). Students program this equation in the software and generate a gray scale raster image with values between −1 and +1 where high values (light areas) indicate snow (Fig. 1b).

This exercise is broken down into a series of parts and alternative implementations are provided to shorten and/or simplify the exercise as desired. Students gain experience with level 2 and 3 products and with constructing models (visual representations of computer programs) to manipulate and analyze the satellite data. The exercise demonstrates how snow maps are produced, and how students can use them to investigate the effects of climate change on snow cover and water resources. Figs. 1(a)–1(f) present an example of typical steps students might undergo in a tutorial; in this example the figures show the image products generated as students map snow cover.

Tutorial 2: Mapping sea ice using a microwave imager/sounder (SSMIS)

Sea ice concentrations are important to monitor because ice is sensitive to changes in temperature and thus is a strong indicator of climate change. In addition, like snow, sea ice reflects sunlight keeping the planet cool, and thus influences climate through the albedo effect. If ice melts, more heat from the sun will be absorbed and the planet will warm causing more ice to melt. This perpetuates a positive feedback loop of more warming and more melting (Screen and Simmonds, 2010). These changes have important ramifications for all life on Earth, especially Arctic and Antarctic ecosystems and Arctic populations who depend on sea ice for hunting and wildlife. In this set of exercises students calculate total sea ice concentration from microwave satellite measurements made at different wavelengths and compare their results to a sea ice map available from the National Sea and Ice Data Center (NSIDC) (NSIDC, 2013).

Microwaves are useful for monitoring sea ice because they can be used to collect data through clouds and at night. This is important because during the winter the poles are in darkness. Passive microwave data is particularly useful as it uses the Earth as a radiation source and does not require its own generation of microwaves and an accompanying power source (''active'' sensing). Because there is a large emissivity difference between ice and the ocean at microwave wavelengths it is possible to distinguish sea ice from water, and even first year from multi-year ice (Comiso, 1986). The Defense Meteorological Satellite Program (DMSP), a joint operation of the Department of the Defense, Department of Commerce, and NASA, includes satellite instruments to monitor meteorological, oceanographic, and geophysical environments (NOAA, 2013). The Special Sensor Microwave Imager/Sounder (SSMIS) instrument is employed in this exercise as it provides daily coverage at 25 km spatial resolution.

Students download brightness temperature data for the 19, 22, and 37 GHz channels of SSMIS from the NSIDC. (Radiation from an emitting body is normally reported in terms of ''brightness temperature''. For good absorbers and emitters, this will be close to the actual or ''kinetic'' temperature of the body. For poor absorbers and emitters it is dependent on both their emissivity and true temperature.) Students use a model to build and execute a series of equations which calculate polarization, spectral gradient ratio, first year ice, and multi-year ice cover. From these they compute the total sea ice concentration and generate a gray scale image showing the sum of first year and multi-year ice.

This exercise is broken down into a series of parts and alternative implementations are provided to shorten and simplify the exercise as desired. Students gain experience with level 1 (brightness temperatures) and level 3 (sea ice map) products and with constructing models. This exercise demonstrates how sea ice is mapped by NSIDC and used to monitor climate change.

Tutorial 3: Mapping global carbon dioxide concentrations, temperature and ozone using AIRS

Atmospheric gases such as carbon dioxide, ozone and carbon monoxide are important drivers of climate change, stratospheric ozone depletion, and air pollution (Turco, 2002). Together with other atmospheric variables such as temperature and humidity, they can also be important components of broader environmental studies. In this set of exercises, students learn how to incorporate global monthly maps (Level 3 products) of atmospheric data in ArcGIS for use in environmental studies, spatial analyses, and to monitor global change.

A primary source of atmospheric constituent and climate data is the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua satellite that is part of the Earth Observing System (NASA EOS, 2013). It monitors temperature, humidity, and a host of atmospheric gases including carbon dioxide and water vapor by measuring infrared radiation emitted from the Earth and its atmosphere at 2,378 different wavelengths. AIRS has a spatial resolution of 13.5 km and provides daily global coverage.

The two exercises are tutorials which guide students through the AIRS website to download carbon dioxide, ozone, and temperature data via the Mirador data search tool (NASA Mirador, 2013). Data are obtained in NetCDF (Network Common Data Form) and HDF (Hierarchical Data Format) formats common to many remote sensing data sets. Students employ interpolation tools within ArcGIS to display carbon dioxide concentrations.

In a second exercise ozone and air temperature data are downloaded in HDF format, which also contains many different data layers in a single file. In this case the HDF file contains both ozone and temperature data which can be added directly to the map within ArcGIS.

These exercises provide useful tutorials for those wishing to incorporate atmospheric data into other studies, or conducting trend or spatial analyses of the data themselves.

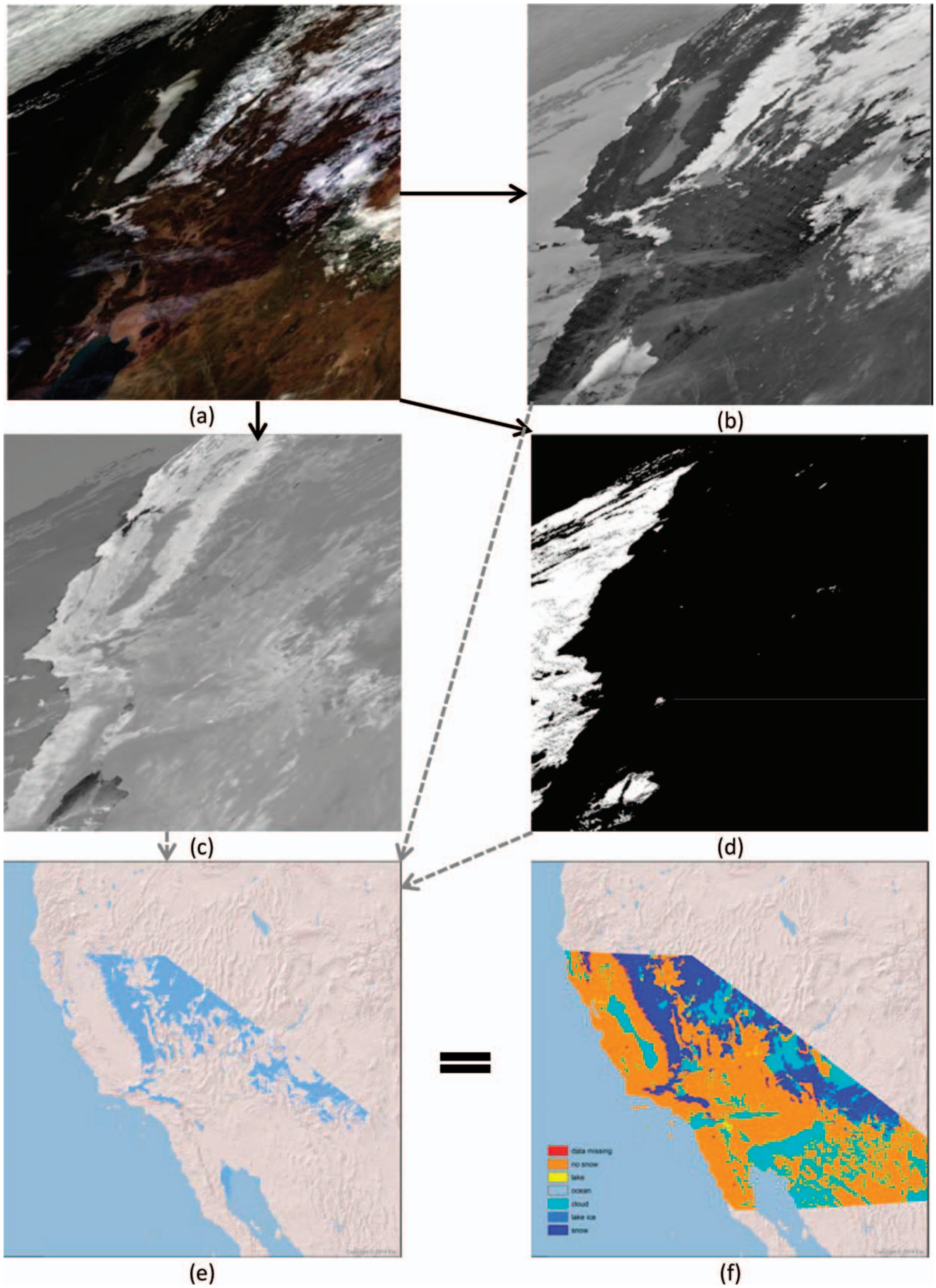

FIGURE 1: (a–f) Images show some of the processing steps in the generation of a snow cover map in the Sierra Nevada mountains. (a) The downloaded MODIS image for January 4, 2011; (b) The Normalized Difference Snow Index (NDSI) generated from (a); (c) The Normalized Difference Vegetation Index (NDVI) generated from (a) and used to make corrections to the snow map; (d) the water mask generated from (a) and used to make corrections to the snow map; (e) the student-generated binary snow map re-projected for California after corrections for forest and water have been made using (b), (c), and (d); (f) NASA's snow product map.

Tutorial 4: Using Landsat to examine deforestation in Brazil

Forests play an important role in removing carbon dioxide from the atmosphere and thus help to mitigate climate change. The carbon that trees sequester from the atmosphere is stored in biomass as leaves, bark, and branches. When deforestation occurs the stored carbon is released as carbon dioxide back into the atmosphere as the tree decomposes (Gibbs et al. 2007). The Intergovernmental Panel on Climate Change (IPCC) has documented the effect of land use and land use change on global carbon dioxide concentrations and warming. Its 2007 report (IPCC, 2007) states that land use changes dominated by deforestation (and associated biomass burning) are responsible for 25% of the increase in carbon dioxide concentrations since pre-industrial times. Deforestation is a particularly acute problem in tropical forest areas (much of the rest of the world has already denuded itself of natural forest). In this exercise, students use Landsat data to examine deforestation in the Brazilian state of Mato Grosso.

The vegetation in Mato Grosso is a transition zone between the tropical rainforest of the Amazon and tropical savanna of the Cerrado. Much of Mato Grosso has been cleared for soy farming and cattle grazing (BBC, 2011). Since this exercise was primarily geared towards students studying climate change explicitly (as opposed to remote sensing or GIS), the focus was on understanding, analysis and interpretation rather than on technical skills development. For this reason, students were provided the satellite data (rather than locating, downloading and importing it) and their task was to compute the area of deforestation occurring between 1990 and 2011 and the resultant carbon dioxide emissions. The second part of the exercise led the students through steps to extrapolate their calculations to the whole of Brazil and compare the annual emissions from deforestation in that country to those released by the United States from fossil fuel combustion.

Students first computed the Normalized Difference Vegetation Index (NDVI), first introduced in the early 1970s (Tucker, 1979) to assess and compare green vegetation mass using the red and near infrared bands of a satellite instrument. This metric is almost universally employed in the study of global vegetation health and cover. Students can use a built-in function or program their own model to calculate this index from the Landsat Level 1 data provided. By establishing a reasonable threshold, students separate forested from unforested areas and calculate the areas of each. Further data processing subtracts the 1990 vegetation map from the 2011 one so that the land which has been transitioned from forest to non-forest (or vice-versa) can be seen.

Harris et al. (2012) discuss estimates of carbon stock and the carbon emissions from forests around the world that result when trees decompose or are burned. Students applied these data to calculate carbon loss and CO_2 emissions due to deforestation in the area of study. Using a bioregions map, students extrapolate their calculations to all Brazilian tropical forest areas. Projections from this exercise are that resulting annual CO_2 emissions amount to approximately 1.7 Gt CO_2/yr^{-1}, a value roughly 30% of total U.S. emissions. Through calculations students put these data in the context of global emissions and start to comprehend the significance of the role that forests play in controlling our climate.

Tutorial 5: Using GRACE to evaluate change in Greenland's ice sheet

Gravity Recovery and Climate Experiment (GRACE) is a joint operation by NASA, German DLR, and European ESA space agencies in which two satellites orbit the Earth 500 km (311 miles) above, measuring its gravity field. The two satellites are separated by approximately 220 km on the same path with one ahead of the other. Variations in the gravity field change the distance between the two satellites, which is measured using a microwave instrument that sends a beam between the two satellites. Changes in the satellite separation as small as 10 microns (a fraction of the thickness of a human hair) can be detected. These changes are used to generate a gravity map of the Earth which can be employed in a variety of applications including water resources, tectonic movement, ice and glacial mass, and sea level fluctuation. In these exercises students use GRACE data to explore how the Greenland ice sheet mass changes throughout the year in response to seasonal temperature variations and how its mass has changed over the past decade as a result of climate change. These exercises were designed to familiarize users with the GRACE satellites and data, and to teach image analysis methods in GIS and remote sensing, including the animation of a time series. They also served to provide a platform for discussion on the effects of climate change on the Greenland ice sheet and its concomitant effect on sea level.

Exercises employ the Level 2 monthly mass grids (derived products), which are observed changes in land mass. Much of the change in gravity is caused by changes in water storage in hydrologic reservoirs, by moving ocean, atmospheric and cryospheric masses, and by exchanges among these reservoirs and these mass changes can be thought of as equivalent to a very thin layer of water concentrated at the surface whose thickness changes. Thus the data is expressed in units of equivalent water thickness (mm).

Data were accessed through the GRACE (2012) website and imported into ArcGIS for processing. Students evaluate how the ice sheet has changed in recent years by subtracting a 2004 image from a 2011 one and finding the average mass difference for each pixel within the Greenland continent boundary. They use this to estimate the rate of sea level rise caused by ice sheet melt over Greenland. Although these exercises were employed in a remote sensing class, the application again focused on climate change and its effect on the hydrosphere.

Tutorial 6: Using MODIS to analyze the seasonal growing cycle of crops

In this set of exercises students applied MODIS data to the examination of the phenological cycle of crop fields in Colby, Kansas by looking at a corn field and investigating the change in spectral response and NDVI over a period of 3 mo (from August to October). Changes to phenological cycles as a consequence of climate change were discussed in class based on a reading of Myneni et al. (1997) who employed the NDVI to track the greening of the northern hemisphere and showed how it was occurring earlier every year and how the crop cycle had been extended by up to seven days between 1981 and 1991 as a result of global warming. These exercises provided students with a foundation for how one can use satellite data to evaluate and quantify the seasonal vegetation growth cycle, and how this can be used to analyze the effect of climate change on the plant community. One graduate student is now conducting her thesis research on an application of this in the Arctic tundra.

Two MODIS images of surface reflectance (Level 2) per month between August and October 2011 were downloaded. Students learn how to use the spectral profile tool to plot and examine how the spectral signature of corn changes as the season progresses. In the second part of the exercise they learn how the NDVI can be used to assess vegetation greenness and build a model to compute this from two of the MODIS bands. They then construct a graph to show how this index changes throughout the growing season.

This exercise was utilized in a remote sensing class and was designed to familiarize students with a different satellite instrument (other than Landsat, for which most exercises were originally designed) and to teach analysis techniques. The students readily see how satellite data is used to explore global change and much of this change can be attributed to climate change.

Tutorial 7: Fire mapping using ASTER

In this exercise students are introduced to the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on board the Terra satellite. This instrument comprises three sensors, the first of which records three bands of visible and near infrared (VNIR) radiation at 15 m resolution, the second recording six bands of shortwave infrared (SWIR) at 30 m resolution, and the third, the thermal infrared (TIR) radiation emitted by the Earth in four bands at 90 m resolution. ASTER data is only available on an on-demand basis which leads to gaps in its data record, making its utility limited compared to Landsat. However, where data are available the footprint is higher resolution than Landsat's and the additional recorded bands of data improve its range of applications. Its added capability in the SWIR provides the ability to monitor fires and volcanoes, and to map minerals and geology. In this set of exercises ASTER data is used to map wildfire, including burn severity and the re-growth of vegetation, through application of the normalized burn ratio (NBR).

Fires are a common phenomenon in southern California, fueled by dry brush and chaparral and often driven by strong Santa Ana winds. In recent years the frequency of severe fires in the region has increased as a result of various factors including population expansion into formerly undeveloped areas, increased fuel loads, and climate change. According to a California Energy Commission Report (Westerling and Bryant, 2006) wildfires are expected to increase in intensity and frequency as a result of climate change. Wildfires add significantly to atmospheric carbon dioxide emissions, so that the expected increase in their frequency will further accelerate global warming (Running 2006). These exercises introduce students to the methods used to assess wildfire damage, severity and recovery using remote sensing through the study of one particular fire in southern California. Students can apply this methodology to study wildfires and their impact in a future world of increasing frequency.

The Old fire, which was a part of the "fire siege of 2003" when eight wildfires simultaneously burned southern California (Piru, Verdale, Simi, Grand Prix, Roblar, Paradise, Cedar, Otay fires) is used in this set of exercises. The Old fire ignited on October 25, 2003 in San Bernardino County and burned 91,281 acres including the San Bernardino Mountains, Highland, and Lake Arrowhead. The fire was contained on November 2, 2003 by which time nine hundred and ninety three homes had burned and six lives had been lost.

Students used ASTER Level 1b imagery from NASA's Reverb Echo website imported into the ERDAS Imagine software to carry out the assessments of burn severity and vegetation re-growth. Initial and extended assessments of wildfire were conducted by the students. The initial assessment identifies the fire perimeter and severity of the burn using images taken directly after the fire (post-fire image) and a year before the fire (pre-fire image). The difference between those two images will show how much vegetation there was before the fire and how much was left after the burn thereby identifying the extent of the burn damage. The extended assessment examines the re-growth rate of vegetation after the fire. For this, an image is taken just before the fire started (pre-fire image) and is compared to an image taken a year or more after the fire (post-fire image) during the same month as the pre-fire image. This assessment analyzes vegetation recovery.

Students were guided through the download and import of relevant ASTER data, using fire perimeter data from Monitoring Trends in Burn Severity (MTBS), a project sponsored by the Wildland Fire Leadership Council (WFLC) and other agencies to implement the National Fire Plan and Federal Wildland Fire Management Policies (MTBS, 2012). Students learn how a burn index can be defined from a near infrared and a shortwave infrared band. For ASTER the Normalized Burn Ratio (NBR) uses band 3 (0.78–0.86 μm) and band 6 (2.185–2.225 μm) for the computation: NBR = (band 3 − band 6)/ (band 3 + band 6). After a fire, the SWIR (band 6) reflectance increases and the VNIR (band 3) reflectance decreases. An NBR grayscale image thus shows the burn area as a dark grey area.

The Differenced Normalized Burn Ratio (dNBR) is the difference between the NBR images pre- and post- fire. The initial dNBR shows the burned areas and is often used to delineate the fire perimeter, whereas the extended dNBR measures the regrowth of vegetation after the fire. Students construct a model to calculate the dNBR and code the images in ArcGIS to display burn severity. They compare their derived products with those from the MTBS site to complete the exercise.

Student Satellite Presentation

In the undergraduate remote sensing class, one of the methods used to introduce students to the range of satellite instruments and data was to have each student research and prepare a short (10 minute) presentation on an assigned instrument. They each had to report on date of launch and activity, orbit type and altitude, spatial, temporal, spectral and radiometric resolution, provide a sample image from the satellite and research its applications.

Remote Sensing Application Project

In the graduate seminar in remote sensing all students had to conduct individual or group projects of their own choosing. They were encouraged to use their newly acquired skills to experiment with a different satellite instrument or apply a different technique to a satellite data set already used in class. Students' favorite projects have traditionally included land cover and land use change classification, fire mapping, and vegetation studies using Landsat data. Since the introduction of several other satellite instruments over the past two years an increasing number of students have been more ambitious and carried out projects using alternative data sources. These include ASTER, SeaWifs, MODIS, GRACE and SSMIS which they have used these to study fire recovery, El Nino, land cover, ice sheet and sea ice mapping.

In the next section, the implementation of these exercises in three course settings is described, along with procedures for the collection of evaluation data from consented students enrolled in each course.

METHODS

Curriculum Implementation in Geography Courses

Exercises were implemented in three different geography classes—advanced undergraduate Global Warming, advanced undergraduate Remote Sensing and a graduate seminar in Remote Sensing between Spring 2012 and Spring 2013, with course enrollments listed in Table I. A total of 74 students participated in the courses to date and were recruited through an informed consent procedure at the beginning of each semester. Demographic data for the CSUN Geography Department in Fall 2012 (Office of Institutional Research, 2013) indicate that 29.2% of students identify themselves as white, 42.0% as traditionally underserved (includes 35.3% Latino/a), 11.0% as Asian, and 17.8% as Other. Males in the department outnumber females by a ratio of 1.72:1. These numbers are representative of the student populations of the courses.

There was a wide range of prior knowledge and skills for students entering the courses. For the remote sensing courses, nearly all students had prior experience in GIS but not in remote sensing or image processing. For the undergraduate course in Global Warming, most of the class had a little GIS experience. Only a few of the students in any of these courses had taken any coursework in climate change. All but two students enrolled in the Global Warming class were geographers, and had received formal training in spatial literacy and one entry-level GIS course. They had very little prior understanding of the electromagnetic spectrum or radiation properties, although the two non-geographers were from Applied Math and had received such training. Students enrolled in both the undergraduate and graduate remote sensing courses were primarily geographers but also included anthropologists, archaeologists, applied math, and computer science majors. Hence the skill-set was more varied.

Table I shows the relative cognitive emphasis on four learning objectives for the exercises implemented in each course, where A represents Awareness, D: Development and M: Mastery. Awareness activities are those for which students are given the information or a process is modeled for them without their active participation. Development activities engage students in developing skills in a highly-scaffolded context. So students might learn how to create measures of climate variables or recreate available higher level products under the guidance of the instructor. Mastery activities require students to apply what they have learned to their own projects or carry out tasks in an unguided context.

The focus of the global warming class was to teach climate science, evidence for warming, projections, and mitigation, with a culminating renewable energy project. Thus, activities were less focused on remote sensing methods and skills and more on how to interpret and understand these data—the basis of much scientific knowledge on climate change processes. Thus, the tutorial on deforestation in Brazil only focuses on student awareness of objectives 1 and 2, development of objective 3, while promoting mastery of objective 4.

The undergraduate remote sensing classes generally emphasized mastery of objective 1, development of objectives 2–3 and awareness of objective 4, with emphasis on the satellite technology and data processing and analysis in a highly scaffolded manner. The graduate remote sensing seminar emphasized the application of methods to study climate-relevant environmental variables, and ultimately to student-generated investigations in a culminating course project, requiring mastery of objectives 1–3. Many of the student projects were relevant to climate change (objective 4). By specifying the lessons as emphasizing mastery, development or awareness around each learning objective, the authors provide a framework in which future extensions of these lessons are planned, leveraging the use of these exercises in flexible ways across the educational spectrum depending on pedagogical needs and audience composition.

Initial Evaluation of Implementation

Program evaluation conducted as part of grant activities provided opportunities to collect data on the four learning objectives as part of a larger grant effort. Pre- and post-course surveys provided student perspectives about the courses and their learning. The content of the surveys used in each course reflected the objectives emphasized for development and mastery in each course. Thus, for the Remote Sensing courses, requested feedback focused on learning objectives 1, 2, and 3, while the Global Warming course emphasized questions around learning objective 4.

Surveys for the remote sensing courses consisted of four 5-point Likert rating scales and six open-ended questions designed to assess changes in familiarity and understanding of core content like the properties of electromagnetic radiation and how it interacts with the Earth and its atmosphere, as well as applications of remote sensing in general and specifically to the study of climate change. Students rated their awareness of NASA's role in collecting and analyzing climate data through its satellite missions and rated their own confidence to engage in conversations about the science of global climate change. A copy of the pretest survey questions is available at https://docs.google.com/forms/d/1uLAF3afTWHVJe5LU761tyJgX49Pz0YqdF0wIRYI3bfA/viewform. The post-test survey was similar, and included some additional open-ended questions about overall student experiences in the course as well as the perceived accessibility and user-friendliness of the satellite data used in the tutorials. A copy of the post-test survey questions is available at https://docs.google.com/forms/d/1-U6kbaV0hhKGUfIiEMrCvsr9YsKYrRgC_Raw26Vqbc/viewform.

For the Global Warming course, an instrument adapted from Lambert et al.(2012) assessed changes in content knowledge about key climate change concepts. This instrument is available in the additional online materials for this article. This particular knowledge test has been validated by its authors with pre-service and in-service teachers at the beginning and end of an instructional intervention embedded in an elementary science methods course to assess knowledge about climate change. The instrument uses a combination of close-ended factual questions augmented with some constructed-response questions to open-ended prompts. Student responses to all surveys were graded by the course instructor, and changes over the semester were examined.

Student performance on the tutorials and projects was also considered. For tutorials, students were graded on their ability to successfully produce and interpret relevant data products. An important feature of the tutorials is that they end with the same products regardless of the cognitive level of implementation. The cognitive difficulty is manipulated primarily through the scaffolding of the activities. Less scaffolding increases student responsibility for fulfilling each learning objective and thus increases the cognitive demand of the activity. Performance was therefore judged by the instructor as students implemented the activities in class, and is reported as a cognitive rating of Awareness, Development, or Mastery for each learning objective of each tutorial as to how students were actually engaged in meeting this learning objective, and whether it matched the desired cognitive level of the tutorial as planned (Table I). The instructor also identified specific learning difficulties displayed by students when completing the assigned tutorials.

Finally, graduate student performance on culminating course projects reflected students' ability to learn and apply their knowledge and skills to studies of their choice. Since the choice of specific topic for final projects was left up to students in the advanced remote sensing course, a content analysis of student projects illustrates the range of satellites used by students to answer environmental questions, such as mapping changes in arctic sea ice over the past decade.

RESULTS

Survey Results

Undergraduate Global Warming Course

Total scores were calculated from the *Knowledge of Global Climate Change* (KGCC) inventory (Lambert et al., 2012), administered before and after the Global Warming course. The scores were composed of the correct answers to 20 multiple choice questions, scored 1 point each, and five open-ended questions for a total of 26 points, for an overall total of 46 possible points. Percent correct was used to represent scores in a repeated measures ANOVA with two test occasions (pretest vs. post-test) and two question types (multiple choice versus open-ended). Student knowledge scores ($n = 18$) increased significantly from pretest ($M = 59.9$, SE = 3.2) to post-test ($M = 78.4$, SE = 2.9), F (1, 17) = 33.26, $p < 0.01$, $\eta_p^2 = .66$. Neither the main effect of question type nor its interaction with test occasion were significant. Thus, students showed substantial gains in content knowledge from pretest to post-test, and this was evidenced both in multiple choice and open-ended questions on the KGCC.

Undergraduate and Graduate seminar in Remote Sensing

All of the students in remote sensing courses answered four Likert scale questions on a five-point scale about remote sensing and climate change awareness, confidence, and understanding. The four self-report questions had a Cronbach's alpha of .788 on the pretest and .760 on the post-test and a principal components factor analysis confirmed that all four questions loaded highly on one component in both the pretest and the post-test. The ratings were summed across the four questions (scores ranged from 5–20), with higher scores indicating higher self-reported awareness, confidence, and understanding around concepts of remote sensing technology and its use to study climate change. A 2 (pretest versus post-test occasion) by 3 (course offering) mixed ANOVA on the summed scores revealed a significant main effect of test occasion, F (1, 42) = 54.70, $p < 0.01$, $\eta_p^2 = .57$, with post-test scores, ($M = 13.0$, SE = 0.40) significantly exceeding pretest scores ($M = 10.2$, SE = 0.45).

Further, the main effect of course offering was also significant, F (2, 42) = 4.22, $p < 0.05$, $\eta_p^2 = .17$, reflecting self-reported differences across the three remote sensing courses studied. Post hoc tests revealed that the earliest graduate seminar in spring 2012 received the lowest overall ratings (Tukey, $p < 0.05$) with a mean score of 10.7 (SE = 0.58). The ratings for the undergraduate remote sensing course in the fall of 2012 ($M = 12.7$, SE = 0.56) did not significantly differ from the ratings for the graduate seminar offered in the spring 2013 semester ($M = 12.9$, SE = 0.60). This pattern could be due to instructor improvements in the courses over time, as the trend was for the ratings to increase in the order in which the courses were offered, with the graduate seminar in spring 2012 showing the lowest scores, followed by the undergraduate remote sensing course in fall 2012, nearly equal to the graduate remote sensing course in Spring 2013. The interaction between test occasion and course offering was not significant.

Student Performance on the Tutorials and Independent Projects

In the Global Warming course students met objectives 1, 2, and 3 to the intended levels in Table I. In particular for many it was their first experience with GIS and remote sensing and this exercise provided exposure and experience in the application of numerous techniques. With respect to objective 4, the intended mastery of climate change understanding was likely not met through the exercise itself as most students were more absorbed in technical implementation than in thinking more deeply about the lesson content. In future implementations it would be important to revisit the science content after these exercises are completed in order to emphasize this.

In the undergraduate remote sensing class all four objectives were met to the level intended (Table I) with the exception of mastery in objective 1. The ability to select and utilize the most appropriate satellite for addressing an environmental problem requires exposure to a greater number of satellites than is possible in this introductory course but students were able to make the first step in doing this by identifying the parameters of importance in selecting satellite data to meet a particular application. More of these types of exercises in a variety of applications would need to be carried out by the students in this class in order to gain sufficient experience to be fully successful in independent projects and to move towards mastery in objective 4.

In the graduate remote sensing class, objectives 2, 3 and 4 were met as described in Table I. However, objective 1 was not mastered. Again, experience appeared to be the primary limiting factor. In independent projects assigned at the end of the course, students struggled on three fronts – one was to think carefully about the scale of the project they embarked on and the amount and kind of data that would entail, another challenge was to identify the most appropriate satellite and data set to apply to their problem, and the third was the mechanics of locating the correct data. Most of the students succeeded in these activities but with some instructor guidance. In no case did the students require assistance with the processing of the data once downloaded (objective 3), or the interpretation of the data in answering environmental research questions (objective 4).

Not only were the tutorials largely successful in meeting their learning objectives from the instructor and program evaluator's perspectives, students in the graduate remote sensing course also indicated that the tutorials, including the independent project, were by far the most valuable part of the course, successful in preparing students to transfer knowledge to real world situations. They also indicated that tutorials would benefit from improved accessibility and usability of NASA data sites and more reliable and uniform interfacing with available image processing software.

In the graduate Remote Sensing course, students undertook independent projects at the end of the semester. In the Spring 2013 semester they were encouraged to use a variety of satellite data and to explore new applications by the assurance that their grades would be based not on their study results but on their progress with understanding, processing and analyzing remote sensing data. This had a positive result with respect to the variety of satellite instruments employed in the studies. In Spring 2012, 11 students undertook projects using Landsat, two with MODIS, two with SSMIS and two with four-color infrared aerial photography (some students worked in pairs on joint projects). In Spring 2013 only five students used Landsat data, one used ASTER, one used MODIS, one used GRACE, one used SSMIS, two used SeaWifs, one used four-color infrared aerial photography and one used SMOS (Soil Moisture and Ocean Salinity). Three students employed data for which no tutorials were provided and overall fewer students used Landsat—a satellite with which they are generally more comfortable and have experience.

Course Feedback

Surveys of learning and response to the classes in general were received as part of standard student evaluations conducted annually. These were obtained for the undergraduate remote sensing and climate change courses in Fall 2012. On the question of "The course is valuable for its content, regardless of my grade" students gave a rating average of 4.8 out of 5 for both of these courses (compared to a department, average of 4.3) and on the question of "is among those from whom I have learned a great deal" ratings were 4.6 and 4.4 out of 5 compared to a department average of 4.0. Written comments for both courses were very positive but notably some of the students in the climate change class commented that the GIS/Remote Sensing assignments were useful but that the level of difficulty was too high for those with no prior GIS experience. This is an important consideration in moving forward with further design of exercises.

DISCUSSION

Analysis of surveys and student work indicated that the tutorials were largely successful in meeting their intended learning objectives. Students demonstrated significant increases in core knowledge associated with climate change and remote sensing technology as well as skill development in utilizing satellite-based geoscience data to complete hands-on tutorials and projects related to global climate change and the impact of and on humans. Thus, the tutorials and projects demonstrated ability to provide effective learning activities for advanced postsecondary courses to engage students in climate changes and remote sensing content and skills. Climate change, geographical information systems and remote sensing are all topics generally taught in Geography and Earth Science Departments. The topics can be integrated using exercises such as those described here, to give students hands-on experience with technology, tools and data in a way that will prepare them for future careers in environmental and geospatial studies. It is important to note that climate change was the explicit content for only one of the courses. In this way, these exercises expanded opportunities to explore issues of climate changes in advanced postsecondary students that might not otherwise happen.

While the courses focused on remote sensing technology and image processing as applied to Earth, atmospheric, and ocean sciences, these technologies have broader applicability. GIS is an expanding employment field. According to the U.S. Department of Labor, uses for geospatial technology are so widespread and diverse that the market is growing at an annual rate of almost 35%, with the commercial subsection of the market expanding at the rate of 100% each year (Department of Labor, 2010).

These kinds of exercises can also inspire students to pursue other STEM fields where similar technology can be applied such as image or digital processing in which applications can be found in medicine, radiology, robotics, computer vision, the motion picture industry, etc. For those students in the joint program with the math and physics departments, students learn to apply the theoretical concepts from those classes to real-world problems. Through exposure to direct visual evidence students are more readily able to accept the reality of climate change, gain a deeper understanding, and perhaps convey the message to their peers.

We also see that these tutorials represent excellent examples of the kind of performance expectations espoused by the NGSS (Achieve, 2013), a blend of emphasis on key content ideas like global climate change embedded in activities that engage students in authentic science and engineering practices. Through analysis of authentic satellite data, students of all ages can explore remote sensing with an emphasis on climate change knowledge as well as awareness of impacts of and on humans.

In considering adaptations of the tutorials, a few important points should be recognized. There is a steep learning curve and a fair degree of technical expertise with the NASA data products needed to implement these tutorials with students. While this can initially be trained in higher level versions of the courses or teacher professional development, this will only be a start. Today's students are surrounded by technology that give them access to vast amounts of information, but they need guidance on how to employ the data in their studies in useful and meaningful ways. It is all too easy to become overwhelmed when confronted with such vast data resources. A consistent observation from the remote sensing classes was that students did very well when guided through the web of data resources and options, but struggled when asked to make appropriate independent choices of data and methods. The more exposure and experience that students can gain in hands-on exercises in which increasing degrees of independence are required, the better prepared they are for navigating through the myriad of choices to complete their own research or carry out projects independently later on.

It is well understood that learning by doing generates excitement and interest from students. Students expressed consistent regard for the exercises, their value, and insights about climate change. This makes the tutorials ideal for translation into K12 because we want to reach students before they have decided on postsecondary studies to consider STEM. These tutorials not only provide ways to introduce advanced geography students to climate change, they are now being considered for introductory level undergraduate courses at CSUN due to begin Spring 2015, with the explicit intention to attract students to remote sensing and climate change earlier in their postsecondary career before they decide their academic discipline. In this way these tutorials can be adapted to serve the STEM pipeline, increasing society's climate literacy and stimulating early interest in STEM during K12 years, leading to undergraduate and graduate studies in the geosciences. They keep attention front and center on climate change, one of the most urgent issues facing humanity today.

The mixed-methods program evaluation data reported here demonstrate the effectiveness of the tutorials in achieving their learning objectives. Obviously, examining adaptations of the work into the K12 and introductory undergraduate levels is necessary for validating the use of these tutorials in diverse educational settings. Continuing to study the effectiveness of these curricular tools, however, will require ongoing program evaluation to do more to follow students over time to see in what ways exposure to these tutorials affects their academic performance or career trajectory, and if their exposure to these tutorials makes a difference relative to peers without such exposure.

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