

Linking Physical Geography Education and Research Through the Development of an Environmental Sensing Network and Project-Based Learning

Dar Roberts^{1,2}, Eliza Bradley¹, Keely Roth¹, Ted Eckmann³, Christopher Still¹

ABSTRACT

Geographic education is more effective when students actively participate by developing hypotheses, designing experiments, collecting and analyzing data, and discussing results. We describe an innovative pedagogical approach, in which students learn physical geography concepts by analyzing environmental data collected in contrasting environments in Santa Barbara County, CA. The major components of this approach include a local network of micrometeorology stations (the Innovative Datasets for Environmental Analysis by Students (IDEAS network)), student field trips, a web portal (www.geog.ucsb.edu/ideas) and analysis tools which support student education and research. Examples of student work, graded rubrics, course evaluation scores, and instructor observations demonstrate the effectiveness of this approach. The most serious limitation is the high cost of equipment given the low number of students initially involved, a weakness that can be addressed through expanded use of this facility by other physical geography classes and institutions, facilitated by the IDEAS website, and increased enrollment in existing classes.

INTRODUCTION

Effective geographic education includes active participation by students in the research process (Brey 2000; Carbone and Power 2005; Edelson 2001; Gautier and Solomon 2005; Hays et al. 2000). This approach translates the excitement we feel as scientists into the classroom, while providing tangible student experiences as a supplement to standard course materials. The National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) grant program supports many successful initiatives to improve undergraduate education in science, technology, engineering, and mathematics (Woltemade and Blewett 2002), but few of CCLI's successes have found their way into educational journals to stimulate further innovations. The CCLI program encourages institutions to "adapt and implement exemplary projects developed and tested at other institutions" (Woltemade and Blewett 2002). The development and implementation of the Innovative Datasets for Environmental Analysis by Students (IDEAS) project at the University of California, Santa Barbara (UCSB) Department of Geography represents such a CCLI project. IDEAS incorporates the deployment of micrometeorological stations along an environmental gradient in the Santa Barbara region, field campaigns in a variety of classes, and the subsequent exploration and analysis of data products via web, Matlab, and Excel interfaces.

In this paper, we highlight the specific pedagogical opportunities that deploying micrometeorological stations and utilizing the data in classrooms has afforded via a pilot course (G175: *Environmental Data Analysis*). We also describe the infrastructure and suite of tools developed to facilitate this process. The main research question addressed by this project was "How is undergraduate physical geography education and research improved

through the use of a local environmental sensing network and project-based learning?". The instructional approach explicitly emphasized team formulation of research questions, data analysis, and oral presentation of results. We hypothesized that student learning would benefit from this instructional approach, because it purposefully incorporates the three learning domains specified in Bloom's Taxonomy: cognitive/knowledge, affective/attitude, and psychomotor/skills (Bloom, 1956). The local environment serves as both the setting and inspiration for learning about environmental processes, gaining interest in the research process, and developing the skills to collect and analyze the data. We assess the success of the course using a variety of methods including student survey results, rubric evaluations, and course comparisons.

BACKGROUND

Expectations for physical geography students include understanding key concepts, learning to use relevant software, and applying refined problem-solving skills. Project-based learning is particularly well suited for physical geography instruction with two essential components: 1) a question or problem that students seek to solve and 2) student hypotheses, experimental designs, data collected and analyzed, and the results and conclusions that they may present to others. Project-based learning motivates students and imparts vital skills (Blumenfeld et al. 1991), contextualizes the learning experience, and creates an 'apprenticeship' scenario, which also acts to re-energize educators/researchers (Trautmann and Krazny, 2006).

Project-based learning also offers numerous opportunities for group work, allowing students to practice communication skills and preparing them for the teamwork that many careers require (Livingstone and Lynch 2000). Group work can encompass more thorough investigations and sophisticated research designs than are practical for individual projects (e.g., Simm and David 2002). Students can draw on their own background knowledge and skills to contribute something unique to the group effort, building student self-confidence and creating additional learning opportunities for other group

¹Geography Department and Institute for Computational Earth System Science, University of California at Santa Barbara, Santa Barbara, CA 93106

²Geography Department, 1832 Ellison Hall, University of California at Santa Barbara, Santa Barbara, CA 93106; dar@geog.ucsb.edu

³Geography Department, Bowling Green State University, Bowling Green, OH 43403

members. While levels of contribution and learning may vary among students in the group (e.g., Gautier and Solomon 2005), the logistics of teamwork and division of labor are also important student learning outcomes relevant to real scientific projects at all levels.

For project-based learning, students need access to data and the tools to analyze the data. The use of these and other forms of information and communication technologies (ICT) in science education has been termed "e-Science," and is becoming a high priority at several educational levels (Underwood et al. 2008). The link between teaching and research can become particularly strong when ICT tools and datasets developed specifically for research are used in teaching (e.g. Hays et al. 2000). In conjunction with classroom use of ICT, students benefit from direct exposure to the environments and sensors, which serve as the basis for their research. Field work can also be a particularly good mechanism for providing project-based learning opportunities and helping students to develop skills that are in demand by potential employers (e.g. Shah and Treby 2006).

Micrometeorological tower networks provide an excellent opportunity to combine e-Science tools and field work for the purpose of designing and teaching project-based learning courses. Micrometeorological towers have been deployed by many organizations to monitor a range of environmental conditions, with data available online and accessible for teaching. Use of the American Meteorological Society's DataStreme online data in introductory physical geography weather and climate courses increased student learning and satisfaction (Brey 2000). Such data can be combined with field work opportunities to create project-based learning, e.g. comparing precipitation data from radar and rain gauges (Woltemade and Stanitski-Martin, 2002), as described by the Burd Run Interdisciplinary Watershed Research Laboratory at Shippensburg University (Woltemade and Blewett 2002), a facility used by several departments for a wide range of courses.

The IDEAS project is most similar to the Burd Run Laboratory in that both include field measurements, micrometeorological data and project-based learning. However, the projects also differ in that 1) the Burd Run Laboratory utilizes a single watershed to explore concepts while IDEAS explores concepts by contrasting three environments; 2) IDEAS has a stronger biological focus, specifically on plant responses observed using webcams and actual evapotranspiration; 3) IDEAS relies on access to near-real time data via cellular modem and 4) greater emphasis is placed on exploratory data analysis and tools through the IDEAS website. Through IDEAS, we hope to broaden the discussion on the role of student-led research in integrating environmental sensing infrastructure and classroom learning.

PROJECT DESIGN

Educational Setting

This study was conducted at UCSB, which is a large public university offering undergraduate and graduate degrees in a wide range of disciplines. According to the UCSB portrait (<http://bap.ucsb.edu/IR/>

UCSB_Portrait.pdf), the campus had a total enrollment of 21,410 students as of Fall 2007, of which 17,960 were full-time undergraduate students, 455 were part-time undergraduate students, and the remaining 2,995 were graduate students. At that time, the average age among UCSB undergraduates was 21, with 3% of undergraduates age 25 or older. 54% of undergraduates were women, and 53% reported their race/ethnicity as "white." The overall student-to-faculty ratio at UCSB was 17 to 1, and 72% of undergraduate classes had fewer than 30 students.

UCSB's Geography Department included 23 faculty and 88 graduate students at the time of G175's first offering. This offering of G175 attracted nine undergraduates, consistent with initial upper division course offerings. All nine of the G175 students were geography majors, with two juniors and seven seniors and one woman. We compare G175 to two other similar courses taught by the instructor in the same year, G102 (*Introduction to Environmental Optics*) and G134 (*Earth System Science*). In both cases, the populations were similar with G102 having 18 students enrolled, all 18 of whom were Geography majors, one sophomore, two juniors and 15 seniors and four women. G134 had the most diverse population with 34 enrolled, 27 of whom were Geography majors (7 non-majors), one exchange student, one sophomore, 15 juniors, 17 seniors and six women.

Environmental Setting

The Santa Barbara region provides a unique physiographic setting, consisting of a series of islands to the south, a cold coastal current, a narrow coastal plain, a rugged east-west trending mountain range, and a relatively dry valley in the rain shadow of the mountain range (Fig. 1). This landscape results in several pronounced environmental gradients, including a coastal environment juxtaposed against steep, south-facing slopes, followed by a moderately tall ridge line, steep north-facing slopes, and a fairly arid rain shadow. The general flow of weather systems during the winter results in strong orographic effects, producing enhanced precipitation along the south flank of the Santa Ynez Range and extreme spatial variation in precipitation over short distances. From roughly May to October the "Pacific High" strengthens, leading to large-scale subsidence that creates strong temperature inversions in the area that drive frequent coastal fog and persistent low stratus cloud formation, enhanced by the cold coastal current. The 34° N latitude, when combined with the east-west orientation and steep slopes of the Santa Ynez Range, results in significant differences in solar insolation between the north and south flanks of the range. Because of this combination of geographic features, the Santa Barbara region is an ideal location to study the impacts of such factors as insolation and precipitation on ecosystem properties.

The physical environment and general weather patterns create a highly diverse set of microclimates that impact the distribution of plant communities and species and their seasonal response to temperature and precipitation. Along the coastal plain, vegetation is

dominated by a mixture of introduced European annual grasslands, oak woodlands, minor drought-deciduous shrublands and a mosaic of introduced tree species, and human-dominated covers such as orchards. These highly modified communities rapidly transition to semi-arid, natural vegetation along the south flank of the Santa Ynez Range. Along the north flank of the range, high-elevation, north-facing slopes are dominated by more mesic forests and shrublands, but rapidly transition to semi-arid grasslands and oak woodlands towards the valley floor. Along the valley floor, south-facing slopes are typically dominated by drought-deciduous sagebrush communities while modest slopes and higher elevations transition to a variety of evergreen chaparral species. Sedgwick Ranch, part of the University of California Natural Reserve System, is located in the transition zone between the lower elevation grassland/oak woodlands in the Santa Ynez Valley, and the higher elevation regions dominated by various pines and oaks with additional vegetation heterogeneity created by outcrops of low-nutrient serpentine soils. This wide diversity of microclimates and vegetation communities provides a natural laboratory accessible to UCSB students within less than an hour's drive from campus.

METHODS

In order to determine how a project-based learning

instructional approach, combined with a local environmental sensing network, affects undergraduate physical geography education and research, we focus on the first Geography course at UCSB to extensively use the IDEAS network. This course, G175, was a one quarter-long course taught for the first time during spring 2008 and scheduled to be taught consistently each spring in alternating years. The class consisted of lectures, labs, field trips and student-formulated research. G175 was designed to facilitate student learning through active, hands-on activities, similar to the courses taught using the Burd Run Watershed Lab at Shippensburg University (Woltemade and Blewett, 2002). The course emphasized student-driven research questions and oral presentation of research results to a greater degree than the Shippensburg University project. The implementation of G175 (described in detail below) relied strongly upon the micrometeorological data collected by the IDEAS network, vegetation measurements from supporting field campaigns, and the development of an analyst suite, which enabled students to manipulate the data and synthesize it with class concepts.

Implementation of Instructional Approach

In the G175 course, students were introduced to key physical geography concepts, starting with the sun and energy balance, then progressing through temperature

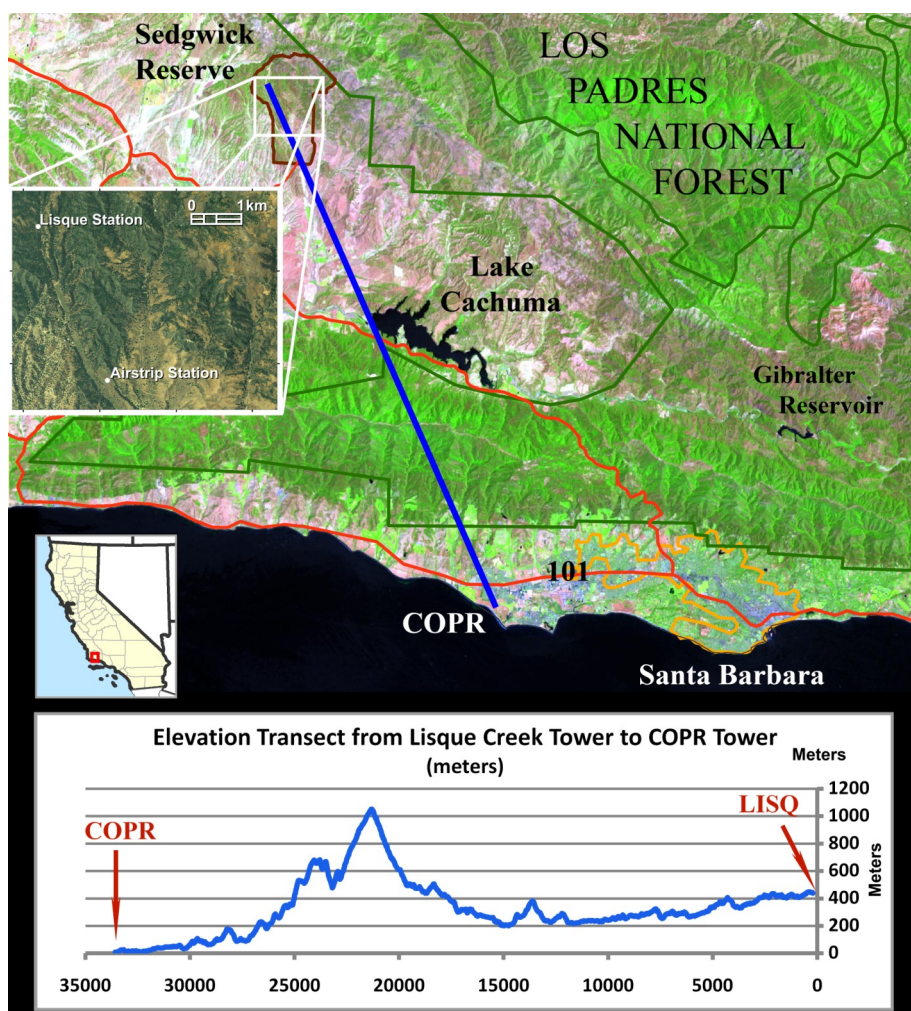


FIGURE 1. Site map showing IDEAS station locations and height transect information overlain on a Landsat ETM+ image acquired in July, 1999. Green regions represent a mixture of chaparral and evergreen oak and pines at high elevation. Grasslands and drought deciduous shrublands are light reddish brown. Bright green, regularly shaped areas along the coastal plain are golf courses and agriculture. The blue line represents a transect connecting the COPR and LISQ towers. The inset on the left shows a blow up of Sedgwick Ranch showing the location of the LISQ and AIRS towers.

TABLE 1. G175 COURSE TOPICS SAMPLE

Topic	Key Concepts	Course Work
Insolation	key controls and multi-scale temporal and spatial variation	lab (1 week)
Energy balance	key controls and temporal and event-driven variation	lab (1 week)
Temperature	variations in air and soil and driving factors	lab (2 weeks)
Water	variations in air and soil and driving factors	lab (2 weeks)

and moisture in the environment and concluding with integrated measures such as evapotranspiration. Student learning was promoted by student-formulated research, in which each concept was explored in lab by student groups who: (1) designed their own research questions; (2) extracted and analyzed appropriate data from the website; and (3) presented their research results. Each student group completed a research paper, in which they were required to utilize field data collected by the class, and study how environmental change impacts vegetation.

Students completed five labs, starting with an initial lab designed to introduce them to tower instrumentation, data available on the website, and graphical and analysis tools (Matlab GUI and Excel templates downloadable from the IDEAS website in the 'Help and User Survey' section). Following the initial lab, students worked in teams to formulate their own research questions and design their own experiments. The instructor and teaching assistant worked with the teams to select a topic which followed key concepts presented in lectures. A sample of course topics is presented in Table 1.

Additionally, students were expected to complete an integrated analysis by combining all the elements of physical measurements to either investigate seasonal changes in soil water balance or seasonal changes in vegetation and evapotranspiration. All students were required to calculate potential evapotranspiration (PET) and incorporate elements of field data collected on April 5, April 26th and May 31st, 2008.

Students, working in groups, were required to develop and present to the class a ~ 20 minute professional presentation for each topic. Presentations were graded quantitatively by the instructor and teaching assistant using a rubric developed by Roberts. Key elements of the rubric included an assessment of scientific content (quality of the science question and scholarship: see online supplement [g175-rubrics-science.pdf](#)) and presentation content (quality of figures, organization of talks, quality of analysis and discussion: see online supplements, [g175-rubrics-presentation.pdf](#)). Each element included a detailed description and specific point value. Students were given a copy of the rubrics to help them design their presentations. After each presentation, students were given a copy of their graded talks and given the opportunity to discuss their performance.

In addition to presentations and laboratory activities, the class included three field trips targeted to train students to collect vegetation information along transects and to use this information in interpreting how vegetation responds to environmental changes. The entire class took

responsibility for all field data entry and analysis. For final projects, students were required to present a 40-minute talk during finals week (as a group) and to submit a 20-page scientific paper. A revised set of rubrics was developed and used for these projects, which placed greater emphasis on synthesis.

The key materials and methods used to implement our instructional approach included the IDEAS micrometeorological tower network, field campaigns, and an analyst suite. While our instructional approach focused primarily on instruction through comparison of verifiable sites, a more regional context could be derived through ancillary data available through links on the IDEAS website, such as satellite observations, Remote Automated Weather Stations (RAWS) and radiosonde.

Micrometeorological Network

The network currently consists of three stations: (1) Coal Oil Point Reserve (COPR), (2) Airstrip (AIRS), and (3) Lisque Creek (LISQ). The station locations are shown in Figure 1 and described in Table 2, with close-up images presented in Figure 2. The basic station configuration, represented by Lisque Creek, consists of an anemometer,

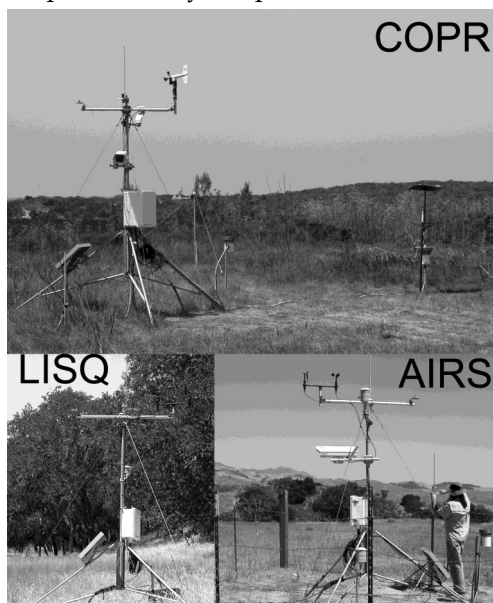


FIGURE 2. Coal Oil Point Reserve (COPR), Lisque Creek (LISQ), and Airstrip (AIRS) meteorological stations. The COPR site is on a coastal plain, LISQ in oak woodland, and AIRS in grassland. The COPR image is all inclusive, showing both the tripod as well as the fog collector, precipitation tipping bucket, and four channel net radiometer. For LISQ and AIRS only the tripod is shown.

TABLE 2. IDEAS MICROMETEOROLOGICAL STATIONS¹

Station	Location	Description	Additional Components
Coal Oil Point Reserve	34.41386 N, 119.8802 W Elev. = 6 m	Coastal plain grassland	<ul style="list-style-type: none"> • Web camera • Four-channel Radiometer (Shortwave and Longwave, Upwelling and Downwelling) • Temp/RH set (Bowen Ratio) • Marine grade anemometer • Basic instrumentation
Sedgwick: Airstrip	34.69685 N, 120.0484 W Elev. =381 m	Santa Ynez valley grassland	<ul style="list-style-type: none"> • Web camera • Net Radiometer • Temp/RH set (Bowen Ratio) • Basic Instrumentation
Sedgwick: Lisque Creek	34.72449 N, 120.0635 W Elev.=430 m	Santa Ynez valley oak woodland	<ul style="list-style-type: none"> • Basic instrumentation

¹All stations are equipped with basic instrumentation including at least one air temperature/relative humidity sensor, soil temperature and moisture probes at three levels, tipping bucket gauges (precipitation and fog), a pyranometer, anemometer and leaf wetness sensor.

pyranometer, tipping bucket precipitation gauge, fog collector, soil moisture and temperature probes at three depths, leaf wetness sensor, and one temperature/relative humidity probe. The sensor sampling rate is 30 seconds with synoptic (average, total, maximum as appropriate) values recorded every 15 minutes. The fog collector is connected to a tipping bucket for measurement and is described by Fischer and Still (2007).

Additional equipment was integrated into the COPR and AIRS stations to extend analysis including a web camera and a second temperature/relative humidity probe required to estimate evapotranspiration using Bowen ratios (Bowen 1926). COPR also includes a four-channel net radiometer measuring upwelling and downwelling longwave (5 to 50 μm) and shortwave radiation (305 to 2800 nm) and AIRS has a one-channel net radiometer (0-100 μm). All data are transferred by cellular modem.

Field Campaigns

During G175, students visited the three stations and collected field measurements of vegetation composition and phenological state on April 5, April 26th and May 31st, 2008. Spring represents an ideal time for a course like G175 because it captures vegetation while it is still photosynthetically active, yet also represents a period of rapid environmental change. Three approaches were implemented: (1) Standard vegetation transects; (2) Digital images of vegetation, and; (3) Canopy height measurements. Random sampling of vegetation at each site was achieved by establishing transects of fixed length along which a set number of quadrats (fixed areal plots divided into four quadrants) were randomly distributed. For each quadrat, presence/absence of species was recorded. To assess species frequency, the number of quadrants in which a given species occurred was counted, so for each quadrat a value from 0 to 4 was assigned for each species. Cover was defined for each species using a semi-qualitative method called the Braun-Blanquet cover estimate (Braun-Blanquet 1932), which includes six categories of percent cover. For focal species, abundance was recorded by counting all individuals in a quadrat and

characterizing phenology (proportion of buds, flowers, and fruits). To facilitate correct student plant identification, a photographic key was developed for Coal Oil Point and another is under development for Sedgwick Ranch.

Digital images were collected for each quadrat for a square area 70 cm wide that was oriented to minimize shading from the camera and tripod. A gray scale standard was placed in the field of view for standardization purposes during processing. These images were then classified using a Matlab decision tree into green vegetation, non-photosynthetic vegetation (stems and litter), flowers, and shade components (Numata 2006). Results for an image taken at the COPR site on 26 April 2008 are shown in Figure 3.

Analyst Suite

As a major element of G175, students formulated research questions based on observational data from the field and micrometeorological towers, with the meteorological archive updated daily. To analyze the meteorological data, students used a suite of tools including: (1) an online data interface (2) a Matlab GUI, and (3) Excel templates. The online data interface (http://zulu.geog.ucsb.edu/VDV/VV_Frame.php), created with the Vista Engineering's Vista Data Vision software, supports individual and across-site data visualization and basic exploratory analysis via histograms and scatter plots.

Exploratory analysis is further extended through a Matlab Graphical User Interface (GUI), which can be used to investigate general patterns, anomalies and differences across-sites and vertically (e.g., the soil moisture probes at three different depths). The Matlab interface outputs different types of visualizations, including bivariate scatter plots, raster hour-day images, and histograms, and allows students to apply different temporal filters (Fig. 4).

The final analytical tool used is a set of Excel worksheets, which support calculations of integrated variables, such as radiation balance, evapotranspiration, and soil moisture balance. Excel pivot tables enable students to aggregate the data at different time scales. A

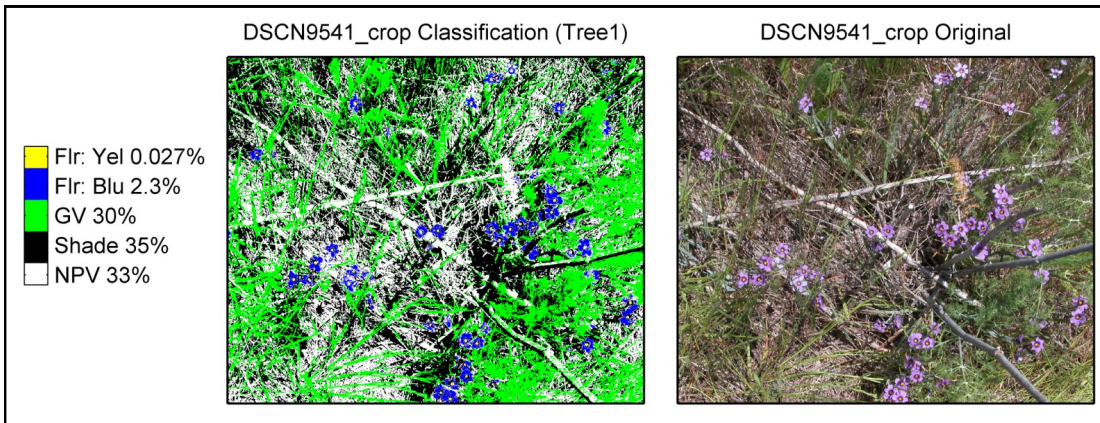


FIGURE 3. Example digital image collected in the field at COPR on 4/26/2008 (right) and classified image (left). The image extent is approximately 70x70 cm. A decision tree was utilized for classification, which was developed from a training dataset derived from a representative subset of the field campaign images.

template Excel spreadsheet includes fundamental environmental calculations and examples ranging from basic temporal-solar calculations (e.g., earth-sun distance, solar position, daylight length) to those needed to estimate a specific variable (e.g., vapor pressure deficit or radiant temperature) and integrated measures (e.g., PET). The full analyst suite including the Matlab GUI and Excel templates are available from the IDEAS website, downloadable from the 'Help and Users Survey' section.

VALIDITY, RELIABILITY AND TRUSTWORTHINESS

In order to assess the validity, reliability, and trustworthiness of our instructional approach we examined several types of information, namely, the students' work and graded rubrics over the term of the

class, anonymous written comments and reviews from the Evaluation System for Courses and Instruction (ESCI) for both G175 and two other physical geography courses taught by the instructor. Additionally, reflections made by the instructor throughout the course were used for synthesis and interpretation.

Example student projects

To provide a measure of the innovation and quality of G175 student research, several example student projects are discussed below (Fig. 5). In all of these examples, the data used by students came either from one of our towers (Fig. 5 a, b, c) or a combination of tower data and student-led field work from spring 2008. In the first example, students designed a research project to test the hypothesis that smoke from local fires resulted in decreased

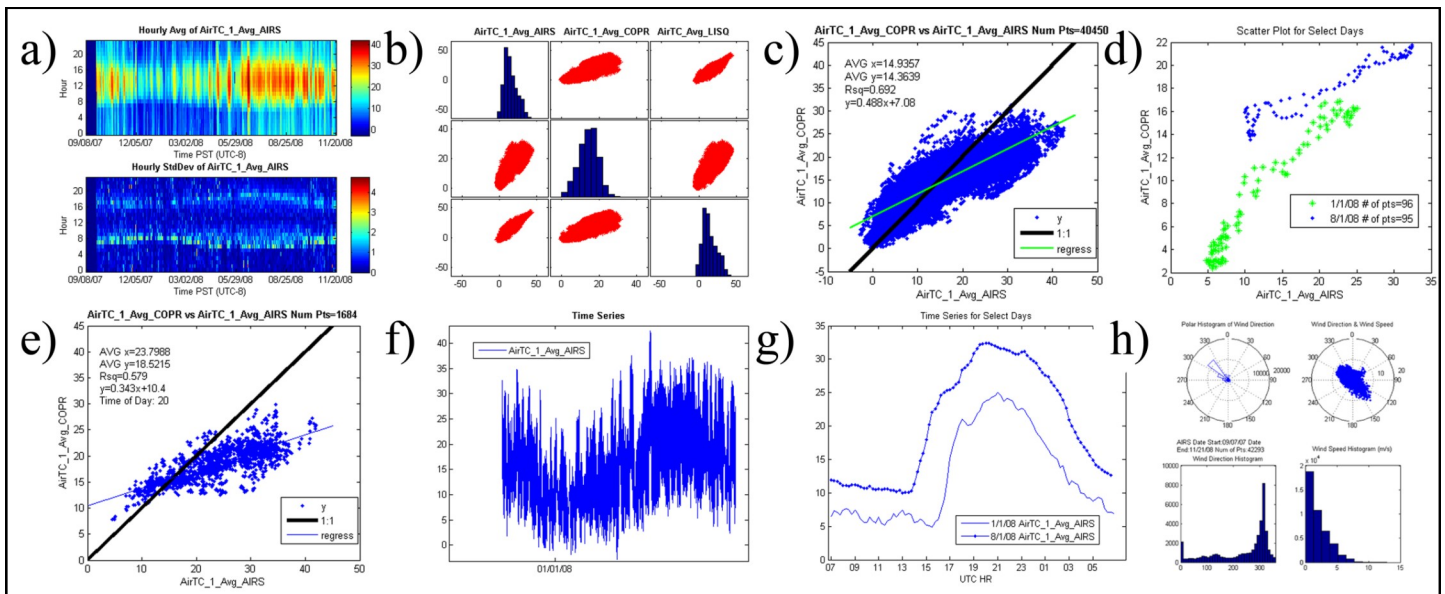


FIGURE 4. Example Matlab IDEAS GUI output. Figures on the upper row include a color graphic a) showing diurnal and daily changes in average temperature and standard deviation, b) matrix scatterplot and histograms for temperature at the three stations, and scatter plots for air temperature at COPR and AIRS for an c) extended time period and d) two days. Figures on the lower row include e) a regression plot between air temperature at COPR and AIRS at 20 UTC, f) a time series plot of air temperature at AIRS, g) a time series plot at AIRS for only two days (shows diurnal patterns) and h) a wind histogram and wind rose.

insolation at the Coal Oil Point station (Fig. 5a). Using internet sources and personal experience, they identified a likely time period when smoke could have an impact on insolation and extracted the appropriate data from the Coal Oil Point station. They further hypothesized that insolation would be most impacted when wind was primarily originating from the north and east and would have little impact when wind was coming from the ocean to the west and tested this hypothesis using wind direction measured by the anemometer. They observed a 76 W m^{-2} decrease in insolation (relative to clear-sky values), consistent with their hypothesis. Wind roses included in Figure 5a were extracted as screen shots using the MATLAB interface while the plot of insolation was generated using Excel.

The second example demonstrates the importance of model development and how environmental observations can be used to better understand departures from the model (Fig. 5b). In this example, the students developed a

model in which solar geometry, earth-sun distance, surface elevation, and atmospheric conditions were used to predict insolation at the LISQ station. A key environmental variable, optical thickness, was derived by comparing measured insolation using the pyranometer at LISQ to modeled insolation over several hours near mid-day. Notable departures were observed in the morning and early evening, where topographic shadowing reduced insolation below the level predicted from solar geometry and the atmosphere. The presence of topographic shadowing, in part, accounts for lower atmospheric temperatures observed at the LISQ station compared to the AIRS station. All calculations were performed using Excel.

The third example illustrates how wind direction and proximity to the coast impact atmospheric humidity (Fig. 5c). In this example, the students observed large diurnal changes in atmospheric humidity (water vapor pressure) at the COPR tower that could not be explained by diurnal

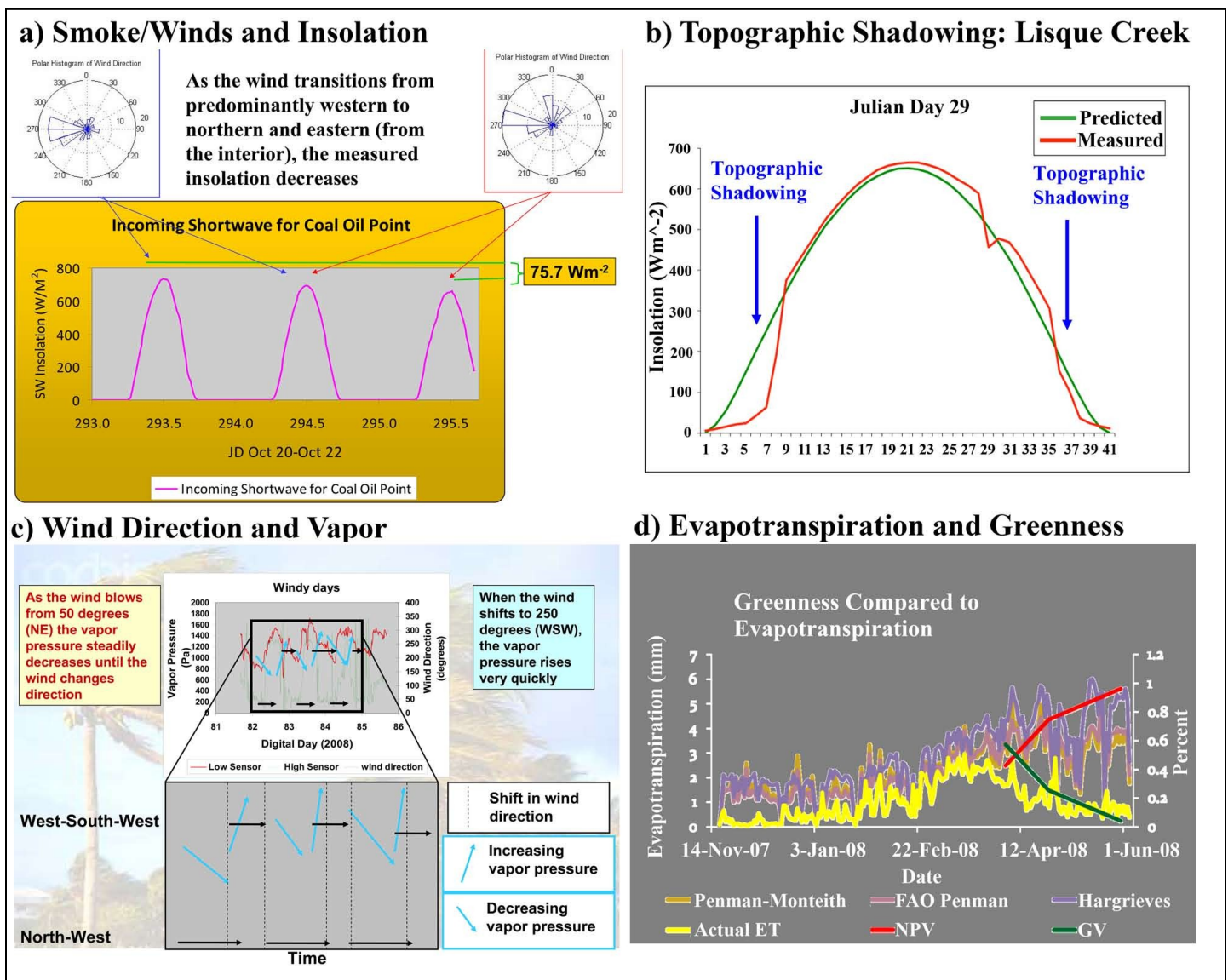


FIGURE 5. Examples of student formulated research derived from G175. Example a), c) and d) were provided by Kyle Ebert, Cheyenne Hadley and Ken Marchus. Example b) was provided by William Dole, Christopher Dorr and Kelsey Lester.

changes in evapotranspiration. They hypothesized that the dominant source of this variability was wind direction, in which wind originating over the ocean would result in higher humidity values, while wind originating from the interior would result in lower humidity values. These observations were further linked to geographic theory, as pressure changes associated with land-sea temperature differences result in pronounced sea-breezes in the afternoon in the Santa Barbara area. They tested their hypothesis using wind data collected at the COPR station, generating their graphics and calculating vapor pressure from humidity and temperature using Excel.

The last example is derived from a final course project, in which students were required to incorporate multiple environmental measures to estimate actual and potential evapotranspiration, and to relate their calculations to field observations of plant cover (Fig. 5d). In this example, the students calculated PET using three methods (Monteith and Unsworth, 1990) then compared PET to actual evapotranspiration (AET) determined using the Bowen Ratio (Bowen, 1926). All of the data used in the calculations came from the COPR station. To better understand why AET decreased while PET increased,

they compared AET to measures of green cover (GV) and senesced plant material (non-photosynthetic vegetation, NPV) taken in the field using digital cameras during the three field campaigns in spring 2008. The students noted a very strong correlation between GV and AET. Additional analysis demonstrated a strong correlation between GV, available soil moisture, and AET, in the process demonstrating the important control that soil moisture exerts on plant growth in the Santa Barbara area. Digital images collected in the field were processed using Matlab Analysts Suite from IDEAS (Fig. 3), while calculations of PET, AET and graphics were generated using Excel.

Rubric Scores Analysis

The students' group projects and presentations were evaluated using the aforementioned rubrics for presentation (group and individual), analysis, discussion (individual), scientific question, and scholarship. The rubric scores were used to determine whether or not the majority of students improved in each of these areas over the course's five group projects. Rubric scores were assessed based on average group scores (by project) and individual scores (student presentation and discussion)

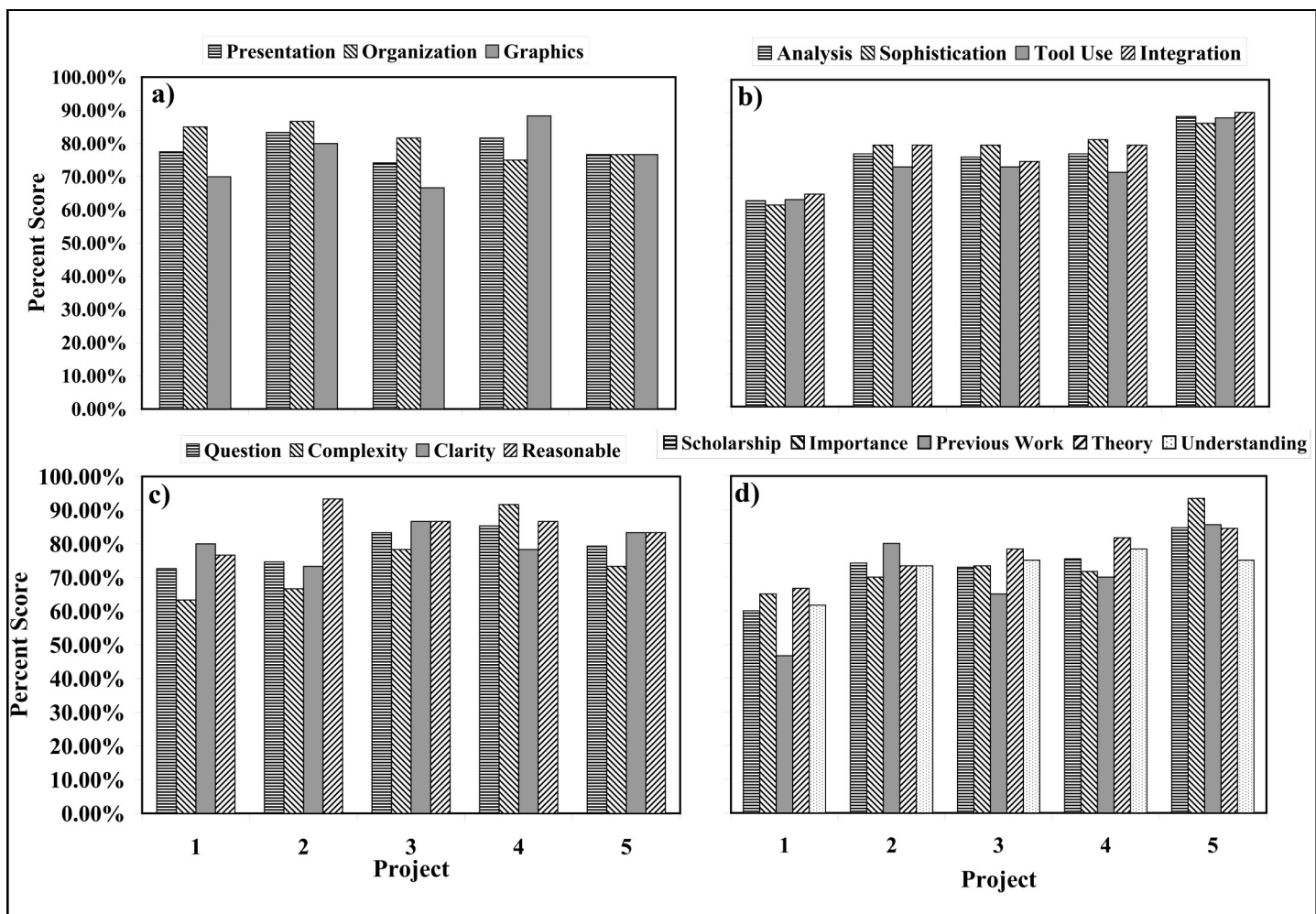


FIGURE 6. Column plots showing the percentage of points for each rubric category earned by student groups averaged for each project including: a) Presentation skills; b) Analysis skills; c) Quality of scientific question; and d) Scholarship. The first column, in each graph reports the average response for a category, while additional columns report performance for a subcategory (e.g., Organization and Graphics subcategories under Presentation).

and plotted over the course of the five projects (Fig. 6 and 7). Group assessment demonstrated no discernable improvement in the presentation category (organization and graphics) over the five projects (Fig. 6a) and only modest improvement in the quality of the scientific questions students formulated (Fig. 6c). Within the scientific question category, the largest changes were observed in the reasonableness of the questions designed (e.g. can it be addressed in the time allowed using the tools available?) and the complexity, with students asking more complex questions as the quarter progressed, but also formulating questions that were more reasonable after the first project. Large changes were, however, observed in the other two categories, analysis and scholarship. In both of these categories, large increases were observed in the sophistication and quality of student analysis and their ability to summarize prior work, establish the importance of the problem and link their observations to theory. In both of these categories, the largest improvements occurred after the first project, followed by similar performance in the next three projects and finally concluding with an improvement in the final project. The largest improvements were found in student presentation of previous work, improving from only 47% of possible points to over 85% by the final project. In contrast to group presentation skills, individual presentation skills did improve as the quarter progressed (Fig. 7). For example, the quality of individual speaking abilities peaked with the final project, whereas the quality of discussion (student ability to answer questions)

improved steadily from the first project to the fourth (Fig. 7).

Course Comparisons using ESCI scores and written comments

Although the small class size prohibits statistical analysis, a semi-quantitative comparison was made between G175 and two other courses taught during the same relative time period (within one quarter of each other) by the same instructor. These comparisons were made using written comments and reviews from the Evaluation System for Courses and Instruction (ESCI), data routinely collected for every class taught at UCSB. ESCI is a university-based service that reports student ratings of courses across numerous categories (Table 3). ESCI ratings follow a scale of: 1-Excellent, 2-Very Good, 3-Good, 4-Fair and 5-Poor, with course mean ratings evaluated in this case and lower values indicative of more positive ratings. This analysis helped isolate course features from instructor differences. Student comments from the ESCI survey were also analyzed and qualitatively compared across the classes.

The 'control' courses, *Earth System Science* (G134) and *Introduction to Environmental Optics* (G102), have some overlap in the concepts taught but differ significantly in the instructional approach used from G175. All three classes are upper division and had modest to low enrollments. All three classes rely heavily on active learning concepts, but vary in the amount of freedom students are given for their research and in the

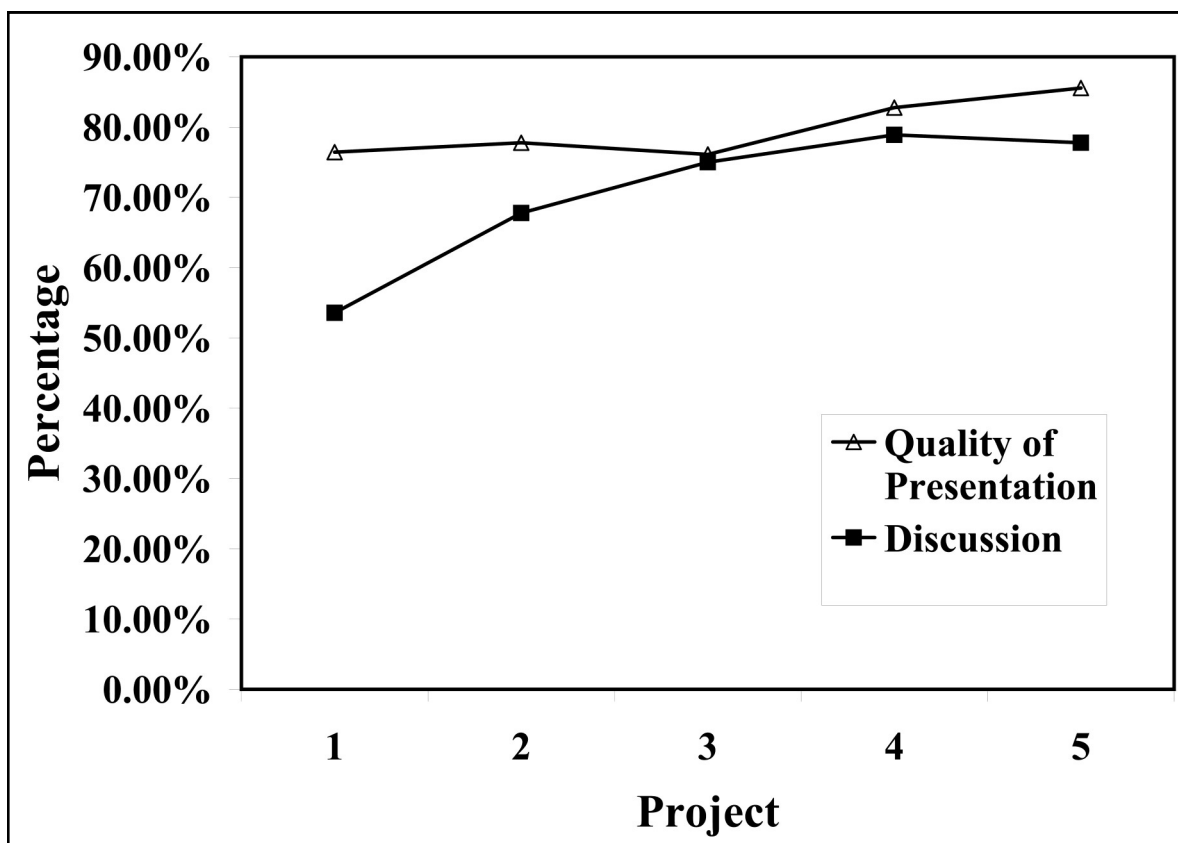


FIGURE 7. Plot showing averaged individual performance for presentation quality (open triangle) and discussion quality (solid squares) for the five projects.

incorporation of student presentations and/or field work. The most constrained course is G102, which relies on pre-designed labs, problem sets and a standard lecture format. For each lab, students collect their own data, but perform the same analysis and complete standard lab reports, e.g. measuring attenuation by absorption using green dye in water. The students work in small groups and share data, but turn in individual lab reports and do not present research to the class. G134, by contrast, provides students with greater latitude in their choice of research. Similar to G175, students are expected to work in small groups and design their own research questions and give presentations that are graded using a numerically specific rubric. G134 student formulated research focuses on different elements of the Earth's radiative environment, ranging from the role of clouds, to aerosols, ozone, or changes in surface cover using an educational version of the Santa Barbara DISORT Atmospheric Radiative Transfer program (Ricchiazzi et al., 1998). This allows students to formulate a research question and run computer simulations to test their hypotheses, but results in a more limited range of topics than G175. Students in G175 have to search a database for existing relevant data and incorporate field observations leading to more open-ended research.

In the ESCI results, students rated the G175 and G102 instructor and course quality as "excellent", with average scores superior to G134, the department and university

(Question 1 & 13, Table 3). The quality of the course was rated slightly better for G175 than G102 (Question 2, Table 3). Students felt the course objectives were most clearly presented and achieved in G102 (Questions 10 & 11, Table 3). The difference students perceived in the course objectives' clarity between G102 and G175 could be a function of the more predetermined nature of G102 and its established history. Overall, G134 was ranked lower than G175 and G102, with the exception of instructor-specific categories, where it was ranked comparably. Students felt that G175 connected the lab assignments and lecture materials very well, better than G102 and G134 (Question 7, Table 3), and also reported the value of the lab equivalent to that for G102 (Question 8). While these results suggest improved performance by G175 in nearly all categories, it should be kept in mind that G175 had the lowest enrollments of the three. Some measure of the potential impact of class size can be quantified by comparing instructor evaluations, which were generally higher (worse) for G134 than the two lower enrollment courses (Questions 1, 3 to 5, 15 in Table 3).

Student written comments for G175 were highly positive similar to the instructor's other classes, with students emphasizing that the experience was challenging but highly worthwhile and noting the instructor's enthusiasm. Comments for G102 indicate that students found this to be the most challenging of the three courses. The sole critical remark for G175 was that "non-

TABLE 3. ESCI RESULTS FOR G134, G102 AND G175 IN COMPARISON TO THE GEOGRAPHY DEPARTMENT AND THE OVERALL CAMPUS¹

#	Questions	G175	G102	G134	Dept	UCSB
1	Overall quality of the instructor's teaching apart from the course materials or content.	1.2	1.2	1.5	2.4	1.9
2	Overall quality of the course, including material or content, independent of the instructor's teaching.	1.2	1.4	2.1	2.5	2
3	Instructor's preparation and presentation of lecture materials.	1	1.1	1.2	1.8	1.6
4	Instructor's clarity and precision of speech.	1.3	1.2	1.5	2	1.8
5	Instructor's ability to make the class challenging and interesting.	1.1	1.1	1.5	2.4	2
6	Emphasis on theory vs. technical skills? 1 (<i>Too much on theory</i>) 2 (<i>About the right mix</i>) 3 (<i>Too much on technical</i>)	2.1	2 (100%)	2.3	2	2
7	How effective was this laboratory section in helping you make connections between the lab assignments and the lecture materials?	1.1	1.4	2	2	1.9
8	How much did the laboratory sessions contribute to the overall value of this course?	1.1	1.1	2.1	1.8	1.7
9	How useful were the laboratory sessions for aiding your understanding of the course material or your ability to apply it?	1.3	1.2	1.9	1.9	1.7
10	The degree to which course objectives were clearly presented.	1.4	1.1	1.8	2.2	1.9
11	The degree to which presented objectives were achieved.	1.3	1.1	1.8	2.2	1.9
12	Instructor's availability for consultation outside of class.	1.3	1.2	1.7	2	1.9
13	Overall course evaluation of the instructor's teaching.	1.1	1.1	1.5	2.2	1.9

¹Students provide ratings on a scale of: 1 (excellent); 2 (very good); 3 (good); 4 (fair); 5 (poor); With mean values presented in the table.

participating group members increase the work load dramatically". Particularly rewarding elements included the personal attention and field days, and the class was seen as a natural progression building upon the G102 course. It was also seen as an excellent addition to the current Dept. of Geography curricula with one student stating, "Geog 175 is a synthesis of physical sciences theory and informational modeling, the only course which focuses on actual and real data, not hypothetical".

While both G134 and G175 gave students flexibility to pursue their own research interests, the only complaints regarding the data and analysis tools occurred in G134. In this case, the students questioned the sole use of SBDART and computer-simulated data, particularly the validity of the model and the lack of alternative models. Students felt its use was not as conducive for conceptual understanding. It appears that the inclusion of real data as opposed to model-based simulations in G175 had a decidedly different outcome in the classroom. For G175 there were no comments on the micrometeorological data's validity or desire for additional data resources, and this effect could be amplified by the location of the network in the students' immediate environment.

Instructor Reflections

Based upon fifteen years of teaching courses in physical geography, the instructor would rate G175 as a highly rewarding teaching experience. The quality of research, as illustrated by student projects (Fig. 5) was very high, demonstrating they gained a good grasp of theory, strong analytical skills, research scholarship and high quality presentation skills. Furthermore, the fundamental hypothesis, that real data acquired in the students' local environment will motivate learning, is supported by the types of projects completed and students' general evaluations of G175. Based on a qualitative evaluation of the quality of student projects, student motivation appeared to be the major element governing the quality of student research. When the students found a research question interesting, they invested more time and effort in the research process. As such, the quality of the resulting research was noticeably higher. The best presentations occurred for projects where all members of a team were involved in choosing the research question and were equally invested in the final outcome. Local events provided the impetus for many research questions. Students would often formulate a question based on something they had either experienced or read about locally, then would develop a research topic that explored the local event (e.g., nighttime fog, local fire's impact on insolation). Internet search engines, combined with data visualization tools on the IDEAS website, enabled students to place these research questions within a more regional context and to draw upon a wide array of source materials.

The field element proved to be highly effective for encouraging student enrollment and motivating student learning. This was expressed both verbally and in written progress reports by students, where most indicated they were motivated to take the course because it included a field element, and stated that they would have preferred

even more field trips, *even if they were on weekends*. Students' confidence in their research skills was reinforced by the field work. For example, statistically significant correlations between student-collected/analyzed field measures of green cover, and tower-based estimates of AET provided tangible confirmation of the validity of both types of observations, and the supporting scientific theory.

Quantitative analysis of rubrics also provides evidence that some elements of the approach were highly effective, including measureable improvements in group scholarship (internet, journal and text research, links to theory and importance) and analysis (use of software tools to analyze data) and individual improvements in presentation skills and discussion. Group presentation scores did not improve while the quality of scientific questions asked only showed modest improvements. The former may be a product of the advanced status of the students (junior and senior) and the extent to which similar presentation skills are emphasized in other geography classes (including G134). The latter reflects the challenges students had throughout the quarter in defining a research question that was both challenging and feasible. We believe difficulties in formulating research questions were exacerbated by the nature of the analysis, in which students are faced with developing research questions from existing observations, rather than selecting a research question before collecting data or relying on controlled experiments.

RESULTS AND IMPLICATIONS

The innovative pedagogical approach used in G175, in which key concepts in physical geography are taught using an active learning model, was promoted through student formulated research with a focus on field trips and student presentations. The course relied strongly upon the use of a local environmental sensing network and the development of a web portal providing ready access to the data and the software tools to visualize the data in a diversity of formats and perform analysis. While a course like G175 could be implemented with class sizes as high as 30, larger sizes would likely be problematic due to the need for access to high quality computational resources. Furthermore, the rubrics used to assess student presentations would need to be streamlined to enable effective grading of larger groups. Other modifications to the approach could be implemented in order to address the needs of a larger enrollment (e.g., not all students give a presentation for each project).

Despite the success of the instructional approach used in G175, its impact was limited by low enrollment. Given the high cost of field equipment and large investment in software development and instrument deployment, more courses and larger enrollments are necessary to ensure a cost effective use of resources. Furthermore, the strong emphasis on quantitative analysis tools in G175 requires students to take courses which prepare them for the use of the analyst suite. However, these current limitations do not detract from the potential instructional benefits of the IDEAS website, which provides open access to all data, background content on environmental observations, links

to a wide array of related websites and access to the same tools used in G175. While another institution may not have the same physical access to the towers afforded by institutions in the Santa Barbara area, they have access to all other elements, including the ability to visualize the sites from webcams (Bradley et al. 2010).

The effectiveness of the approach used in G175 was evaluated using student project examples, rubric grades throughout the duration of the course, and ESCI student ratings for G175 in comparison to other courses taught by the instructor. However, it is important to note that the ESCI ratings and comments did not enable students to give a direct cross-course comparison, and course enrollment was likely a key factor in these results. In order to further investigate these findings, it would be useful to assess the G175 course format led by different instructors, for variable class sizes, and at other institutions. By doing this, the relative importance and contribution of the G175 components could be assessed, namely: (1) field research (2) local data, (3) student directed research and presentation of results. More insight into the development of students' knowledge, skills, and attitude throughout the course could also be ascertained by incorporating portfolios and journals.

In the future, the IDEAS infrastructure will be used by other geography classes, and by other departments and schools. For example, the UCSB *Field Methods in Geography* course, G194, incorporated several modules taught at the COPR and AIRS tower sites. Tower data have also been recently incorporated into G102, both in laboratory exercises and in take home exams. Several cross-departmental educational collaborations have also been proposed, including development of a series of courses in climate change and plant phenology that would use the IDEAS sites. Active collaborations with East Los Angeles College (ELAC) are in place, with an ELAC field trip to the IDEAS network providing students direct experience of the sites. In principle, a course like G175 could be taught at a community college, given open access to all data and instructional materials, with field access to tower sites the main limiting factor. To counter this limitation, information on instruments and manufacturers is provided on the website specifically to enable other institutions to replicate some or all of the instrumental elements. Such an approach is occurring at ELAC, in which Robert West of the Geography Department was able to obtain funding to deploy a similar weather station at the Gold Creek Ecological Field Station, in the San Gabriel Mountains (installed 7 May 2010). We are currently in the process of incorporating this station into the IDEAS online network. This will enable ELAC students to compare data acquired from a local station they can visit, to similar stations located farther north and closer to the coast. While a course like G175 could be developed, Robert West of ELAC has expressed interest in developing curricular materials that support a broader set of subjects in Environmental Science, Physical Geography (labs) and Meteorology. Future curriculum development using the IDEAS infrastructure will benefit from the growing quantity of available data.

Our current efforts aim to expand the network to

include more tower sites and instrumentation, to develop methods for performing more quantitative learning assessment in courses that utilize the IDEAS network, and to expand the use of these data and the website to other classes at UCSB and off campus. Courses which have already used the IDEAS network have been small, upper division courses; however, we intend to design materials suitable for large enrollment, lower division classes not only at UCSB but also on other campuses. While there are numerous opportunities to further expand this project, many benefits are already apparent. The instructional approach used in G175 demonstrates how physical geography education can be effectively linked with research through the development of micrometeorological infrastructure (IDEAS towers), online resources and data access (IDEAS website), field campaigns, and project-based learning. Through this synthesis, both education and research aspects are strengthened.

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