

## FROM THE GROUND UP: DEVELOPING AN INTERDISCIPLINARY COURSE FOCUSING ON MATERIALS SCIENCE AND SOCIETY IN GREEN TECHNOLOGIES

Meredith M. Murr<sup>1</sup>, Stacy E. Patterson<sup>2</sup>, Evelyn L. Hu<sup>3</sup>, Fiona M. Goodchild<sup>1</sup> and Patrick McCray<sup>4</sup>

<sup>1</sup> California NanoSystems Institute, University of California, Santa Barbara, CA 93106

<sup>2</sup> Department of Mechanical Engineering, University of California, Santa Barbara, CA 93106

<sup>3</sup> Applied Physics and Electrical Engineering, Harvard University, Cambridge, MA 02138

<sup>4</sup> Department of History, University of California, Santa Barbara, CA 93106

### ABSTRACT

We have developed a series of three interdisciplinary courses that explore the interplay of science, technology, and society. We designed these courses to be interdisciplinary "from the ground up", in all facets of development: course design, instruction, and audience. This article presents the method of our pedagogy development, followed by an overview of one course (Green Works: Exploring Technology and the Search for Sustainability). Finally, we discuss the evaluation of the Green Works course and present lessons learned as well as recommendations for adoption of this method at other institutions.

### INTRODUCTION

In a society that depends so extensively on the development and use of sophisticated technology, where economic, legal and civil choices become intertwined with technological concepts and alternatives, it is imperative that all students (not just those planning careers in science and engineering) be schooled to achieve a commensurate degree of scientific and engineering literacy. Such literacy today must be placed within the broader scientific context of understanding across several formerly distinct scientific fields, and also within the even more expansive context of societal acceptance, usage, and transformation.

Much of the concern about education in the Science, Technology, Education, and Mathematics (STEM) disciplines focuses on training of future scientists, engineers, and a technically skilled workforce.<sup>1,2,3</sup> However, given the pervasive influence of science and technology on our lives, one could argue that every college student in the U.S. today should have some introduction to basic technological principles such as how a solar cell, computer, or mobile phone works. Moreover, appreciation of the scientific process, the role of creativity, and innovation should be heightened by better understanding the impact of those inventions on our quality of life and the way we organize our

lives. However many non-STEM students are turned off by science. They may not even be aware of how much their lives are influenced by scientific innovation and may think that science, engineering and technology have no relevance and are 'not for them'. This presents a challenge for engaging students in critical discussions of the role of science and technologies in our lives.

In addition, the complementary role that society has in shaping technology is important, and largely neglected by both undergraduate students and the general public. Society's relationship to technology is dynamic and unpredictable, shaping the technology landscape in an intimate way. In other words, the ideal manner of presenting technology to students would consider the reciprocal ways in which technology and society co-produce one another.

Within typical educational institutions organized around distinct academic departments and disciplines, creating courses that embody scientific and mathematical accuracy, credible economic and sociological analysis, and valid historical perspective constitutes a formidable challenge. In this paper, we describe an approach to undergraduate course design where science and technology are presented naturally integrated with the societal context (e.g. history, economics, personal choice, etc.). We developed three courses using this approach focusing on three separate technology areas: surveillance technologies, green technologies, and the technologies of earthquake monitoring and emergency response. These courses all share the same goal: to generate a holistic understanding of technology and society as they relate to a particular area of innovation. They were designed by an interdisciplinary team of instructors "from the ground up", so that in each stage of course development (from the course motivation to instructor selection to curriculum design to instruction methods to the undergraduate audience), there was an interdisciplinary and integrated focus.

This approach has several benefits. First, focusing on a technology in the marketplace

allows flexibility to narrow the course content which is not constrained by the need to cover a predetermined range of content (as, for example, in previous courses for majors). In addition, the topic determines the specific scientific and technical concepts that will be taught. This helps students appreciate that knowledge acquisition is part of the discussion. They can see the immediate application of knowledge which affords an additional layer of relevance and motivation. Second, by picking a "hot topic" that is relevant to their everyday lives, students may be more motivated and engaged than in a traditional science or engineering course. Third, an equal emphasis on both scientific and technological aspects and societal context acknowledges the intimate and dynamic relationship that exists between them, while the study of one facet of the enterprise motivates the study of the other.

In this article, we present a series of courses that were designed to address these issues. We describe the method of course development, followed by an overview of one topic in one course (Green Car Technologies) in the Green Technologies Course (Green Works: Exploring Technology and the Search for Sustainability).

## METHOD

### History of INSCITES

In 2005 the U.S. National Science Foundation (NSF) funded the INSCITES (INsights on SCience and TEchnology in Society) project via a Distinguished Teaching Scholar (DTS) Award to Evelyn Hu, a professor of electrical engineering and materials and the Director of the California NanoSystems Institute at UCSB. The DTS award sought ideas to achieve the following: 'foster innovative and far-reaching developments in STEM education, increase awareness of careers in science and engineering, give recognition to the scientific and educational missions of the NSF, enhance connections between fundamental research and education, and highlight the importance to the Nation's future of citizens who are informed

about STEM'.<sup>4</sup> INSCITES was conceived as a way to create intensely interdisciplinary general education courses, focusing on technology and society. This award fortuitously coincided with the founding of the Center for Nanotechnology in Society (CNS) on the campus, a NSF-funded national research center devoted to studying the societal impacts of nanotechnology, of which Professor Hu and two others (McCray and Goodchild) were co-principal investigators. The establishment of CNS was a result of the NSF's interest in studying the social implications of certain emerging technologies out of a concern that the public might be resistant to the adoption of transformative (disruptive) technologies out of societal or ethical fears, similar to what happened in the U.K. with the controversy surrounding the emergence of genetically modified food in the marketplace.

### **The Participants**

In order to create a series of truly interdisciplinary courses that examines science and technology in a rigorous scientific framework, the instruction teams must be energetic, committed, well versed in some important aspect of the material, and yet malleable: willing to venture beyond their disciplines, willing to take on new materials, and willing to try new pedagogical approaches. Each INSCITES course was designed by a team of scholars with interdisciplinary backgrounds "from the ground up". The course design team was composed of two groups: three graduate teaching scholars (GTS) from diverse disciplinary backgrounds who developed the course topic, structure and content, and a mentor team (MT) of four faculty/staff members, who guided them through the process. As these courses were designed to be general education courses, there was also the expectation that the undergraduate students who would eventually take the courses would also have a wide background of disciplinary interests. Therefore, all of the people involved in each phase of the project were carefully selected or recruited to maintain a balance of disciplinary perspectives.

The Mentor Team was composed of a professor of electrical engineering, a professor of the

history of science and technology, the Education Director of both the California NanoSystems Institute and CNS, and an academic coordinator with CNSI and CNS with a background in Chemistry and Molecular Biology. After a recruitment process, which began nine months before the course was to be offered, the MT evaluated applications from prospective graduate students which consisted of a short personal information application, a statement of interest, transcript and a letter of recommendation from their research advisor. The MT then interviewed the five top candidates and made its final selection of GTS by considering scholarly credentials, the level of interest in the intersection of technology in society, the willingness to pursue an innovative teaching experience, and strong communication skills. The final selection of GTS consisted of graduate students in the Departments of Electrical and Computer Engineering, Computer Science, and Chicano studies.

### **The Process**

After a brief orientation program to review the goals of the program and requirements of curriculum design, the GTS met with the MT weekly for two hours to decide on the course topic, structure and content. The development process spanned two quarters (fall and winter) and the course was offered as an undergraduate general education course with no prerequisites in the Spring quarter.

### ***Learning Objectives***

The INSCITES program provides a framework for the desired learning objectives, and these were the foundation for the subsequent course design. Specifically, the courses all revolved around the same goal: to generate a holistic understanding of technology and society as they relate to a particular area of innovation. Therefore, they were designed to explore this theme in the context of each chosen technology topic. This exploration requires students to acquire topic-specific knowledge about each of the technologies, including the following:

- Understanding of basic scientific principles that underlie each technology
- Understanding of the historical context of the technology
- significant inventions, discoveries, advances
- competing technologies
- Study of the current societal, cultural factors linked to the technology
- Understanding of the "state of the art" of the technology and exploration of future directions for the technology

Students also need to develop basic scientific and technical literacy in order to critically evaluate the merits of each technology. Skills that contribute to this are:

- Practice with measurement, presentation, and analysis of data
  - taking measurements
  - creating graphs and charts
  - drawing conclusions from data
  - interpreting scientific data presented in articles, books, news stories
- Exposure to the scientific research process
  - research projects on campus
  - community and advocacy groups
  - local industry

The interdisciplinary nature of this course placed a priority on helping students to develop skills that are necessary for interdisciplinary communication. We believe that this is crucial to appreciating, critically analyzing, and communicating the many disciplinary facets of technology in the context of society. This goal is achieved by designing activities that require written communication (both STEM and non-STEM), oral communication, and interdisciplinary teamwork.

## COURSE DESIGN

In the context of these learning goals, the GTS developed the specific focus and content of each course. The GTS had a high level of independence developing the course, with the MT providing guidance and advice on pedagogical and content issues. During weekly meetings over the span of about 20 weeks, course content and design were discussed and

finalized. First, the GTS chose the technology topic that would be the focus for the course. The topic had to be a pervasive technology that would be integral to undergraduates' lives in order to appeal to and engage the students who would eventually register for the course. After surveying several ideas, they agreed upon a high-level topic overview and then further narrowed the scope from there. The GTS had to make decisions based on the classic tension in course design: covering many topics more superficially or fewer topics in greater depth. In all three years of the program, the GTS decided to take the latter approach because they felt they would be better able to address the learning goals (see section above) using that format.

Each GTS helped shape the content of each lecture and laboratory period, and it was decided that they would all attend all class meetings to contribute their own disciplinary and individual perspectives on the day's activities. This is unlike most team-taught courses that we are aware of, where instructors alternate lecture days and are rarely present to provide counterpoint for the other instructor. In addition, having all three instructors present at each class meeting created a more seamless integration of the different disciplinary facets of the course material. For example, in one single lecture period, the students would be engaged with several aspects of a technology - from scientific underpinnings, to the comparison of other technologies, to political, social, and cultural issues of adoption. In this way, multiple aspects of the societal adoption of technology were addressed in each classroom activity, specifically reinforcing the integrated nature of the technology/society relationship.

Three courses were developed following this "from the ground up" INSCITES model:

- YouTube and Other Big Brother Stories: Technology and Culture of Surveillance in Modern Society
- Green Works: Exploring Technology and the Search for Sustainability
- Earthquake Isla Vista: Technology in the Monitoring and Emergency Response to Earthquakes

All three courses examined the reciprocal interplay between science, technology, and society. This paper focuses on the "Green Works: Exploring Technology and the Search for Sustainability" course since it contains the most materials science content. However, as can be seen in the above list, the variety of courses that have been developed highlights the applicability of this method to other technology topics.

### Course Structure – Green Works: Exploring Technology and the Search for Sustainability

The course was designed for UCSB's quarter system (10 weeks in duration), with two 75 minute classroom periods and one three-hour laboratory period per week. The course was divided into four two-week modules, each focusing on a specific green technology: Lighting and Light Emitting Diodes (LEDs), Green Buildings, Electric and Hybrid Cars, and Solar Energy and Photovoltaics (PVs). Each module provided a holistic view of the focus technology using a variety of activities and materials intended to address the learning objectives stated in the previous section.

In addition, for this course the GTS decided to center on a "big picture" question: What determines the success of green technologies? To facilitate a deeper exploration of this question, each module considered the question

on a different level, going from the personal up to the global scale. Each module stressed a particular perspective, as shown in Figure 1, and addressed issues related to the success of the technology from that perspective.

The Lighting/LED module focused on questions relating to the role of personal choice in the adoption of technologies. Students examined their own decision making process with respect to lighting technologies and considered questions of cost, availability, consumer awareness, form, and function. The Green Buildings module centered on the community and campus aspects of technology decisions and usage, addressing questions about the importance of community awareness of technologies (for example, the campus lightbulb exchange program) and the "not in my backyard" attitude that can disrupt the introduction of large scale technology changes into a community. In the Electric/Hybrid Car Vehicles module, the focus was on the state level, California in particular. Students considered questions about the impact of statewide decisions and initiatives such as the effects of urban planning and suburban sprawl, the impact of state support on technology competition (investing in roadways versus mass transit), and the importance of state legislation like California's efforts to increase the gasoline consumption efficiency requirements for new vehicles. The fourth module,

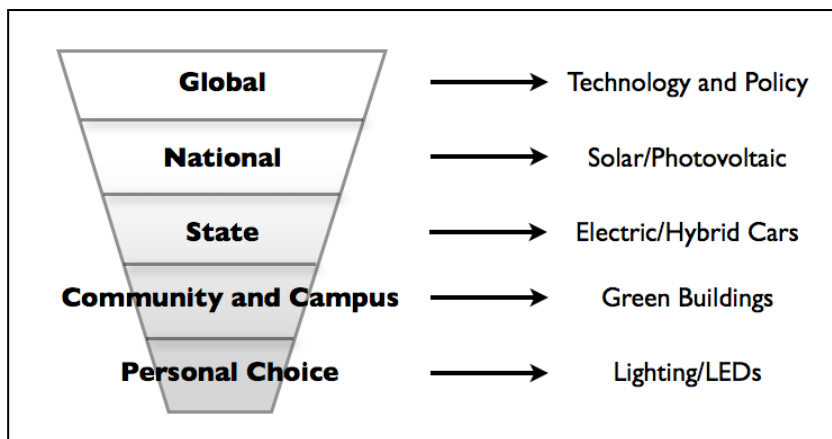


Figure 1. Telescoping View: Multiple levels to analyze the big picture question, from the personal up to the global scale.

the Solar Energy module, explored the question of the success of a technology on a national level, in this case, the United States. Important issues at this level included infrastructure decisions (e.g., the installation of long-range direct current power lines) and whether subsidies are necessary and beneficial for the success of solar technology. After the completion of the four technology modules, two weeks were devoted to discussions and activities relating to the global aspects of the technology question, including the differences between green policy and technology use in different countries and the role and responsibilities of developing nations versus those of developed nations.

All of the activities and the assessment tools were integrated and constructed from the ground up, with the learning objectives as the foundation upon which all aspects of the course were based. Therefore, the GTS were judicious about designing activities that directly related to the learning objectives and the big picture question. The assessment structure of the course was created to reinforce course activities and to measure the student's progress towards the learning objectives. This ground-up approach is illustrated by Figure 2. The major components of the course, discussed below, are: (1) classroom activities, (2) laboratory activities, (3) course readings, and (4) assessment policy.

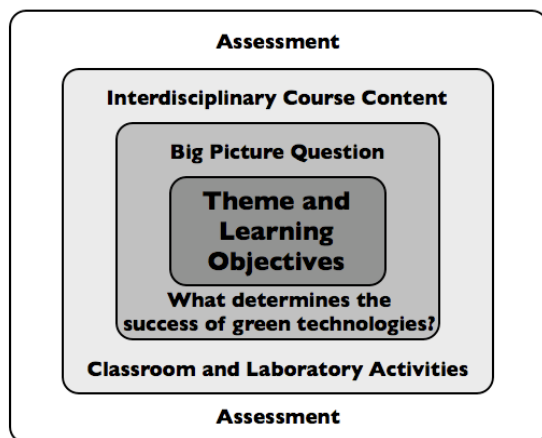


Figure 2. Integration of course materials with learning objectives

### 1. Classroom activities

The GTS designed the classroom activities to be highly interactive, and incorporated multiple alternative modes of instruction to appeal to a variety of types of student learners, including: brainstorming sessions, group problem-solving activities, think-pair-share activities, movie clips, and trivia games. These alternative modes were interspersed to break up more traditional lecture segments into 15-20 minute blocks to keep the students' attention.<sup>5</sup>

Although one GTS had primary responsibility for each class meeting, all three scholars attended every class and contributed to the questions and discussions. By having multiple teachers from both STEM and Social Science/Humanities backgrounds participate in every lecture, students were exposed to multiple perspectives on every topic. Additionally, guest lecturers from the campus and community (such as the campus sustainability coordinator, the energy program director for a local environmental non-profit organization, and leading researchers from the university) provided real-world expertise and perspectives.

The following list illustrates the diversity of classroom topics from the Electric/Hybrid Cars module:

1. The history of the electric car in the early 1900s
  - a. Early competition between gas and electric vehicles
  - b. Environmental and safety concerns about these early vehicles
  - c. The importance of the development of infrastructure for recharging/refueling in conjunction with the development of the vehicles
  - d. The effect of the electric starter on the ultimate success of the gasoline powered vehicles
2. Developing a new electric car: Guest lecturer was the Chief Technology Officer of a local start-up company developing a two-seated electric vehicle.

- a. A first-hand account of the process of introducing a new technology into the market
  - b. The challenges of succeeding in the market, including costs, legal restrictions, competition, and publicity
  - c. The willingness of the public to adopt significantly smaller vehicles even though most commuters travel alone
3. Batteries and the Electric Car
    - a. An overview of the basic science of batteries
    - b. Significant technological advances in battery technology, from the earliest experiments with voltaic piles to current technologies like nickel cadmium and lithium ion batteries
    - c. Future battery technologies using new materials
    - d. The importance of battery capacity and vehicle range to the success of the electric vehicle (public perception of this need vs. actual usage needs)
  4. The Future of Cars
    - a. The future of cars and transportation, as envisioned in popular movies
    - b. A comparison of this envisioned future with actual technology in development, such as underground highways, driverless cars, and flying cars
    - c. Technological hurdles in the way of adoption of these future technologies
    - d. The societal issues related to these "future technologies", e.g. "Would you trust a driverless car to transport your children?" and "What would be necessary to gain this trust?"

## 2. Laboratory Activities

The GTSs developed their laboratory activities to reinforce and expand upon topics covered in the classroom and the learning objectives. For the laboratory periods, students were divided into small groups (3-4 students) which were maintained throughout the quarter. To encourage the students' awareness of multiple perspectives on the lab topics, the instructors organized the groups so that each group

included both STEM and Social Science/Humanities students.

Some of the laboratory activities were traditional science-based activities in which students were required to perform experiments, collect data, and analyze the experimental results. These lab activities followed from, and expanded on, topics studied in lectures. An example from the green car module focused on the science of batteries, following the lecture described in the previous section. This activity was based on the lemon battery activity developed by PBS<sup>6</sup> among others, and the aluminum-air battery activity developed by Modesto Tamez and Julie Yu at the Exploratorium Teacher Institute<sup>7</sup> and was expanded to fit the allotted time and the skills of the students (Figure 3). In the lab, students were given the necessary supplies and written instructions on how to construct each battery and how to connect cells in series and in parallel. They were not told the difference of these two types of connections in terms of voltage and current. For the lemon batteries, students were also supplied with various materials to use as electrodes. Each group was given several specifications of voltage and amperage, and the lab assignment was to create different batteries to meet each of these specifications. To perform these tasks, groups needed to use multiple cells connected in both series and parallel. The students had to collect voltage and amperage measurements for their battery configurations and construct several charts and graphs. The students were also responsible for completing a lab report outside of class in which they had to answer additional questions based on what they had learned, for example, "How many lemons would it take to power an electric car? Is this even possible? Why or why not?". Through this lab activity, the students learned the basics of batteries, current and circuits, and practiced skills such as using the scientific instruments, creative problem solving, measurement and data analysis, and teamwork.

In addition to more science-oriented activities, the course also included some less conventional

lab activities that took advantage of the resources and events on campus and in the community. The 2008 Santa Barbara Earth Day Celebration coincided with the offering of this course and featured a Green Car Show. This event presented an opportunity for students to not only learn about many different types of emerging green vehicle technologies, but also to observe public reaction to these vehicles, and to hear the advertising pitches of the vehicle representatives. As part of the course, students were required to attend the Green Car Show and create a presentation based on their experiences to be given during a lab session. Each group was assigned one of the following green vehicle technologies: electric, bio-diesel, hydrogen fuel cell, ethanol, plug-in hybrids, and high efficiency gasoline engine Smart Car. The students had to research their assigned technology, attend the car show and interview the exhibitors as well as other attendees, collect information from the exhibit, and research additional advertising information about the cars. The student groups then prepared twenty minute presentations which highlighted the information they collected and included their opinions on whether the technology would succeed in widespread adoption. The presentations were graded by the instructors and the other students. This activity required that the students investigate the technologies independently, learn the important concepts, and then present these concepts to the class in a clear and compelling format.

### **3. Course Readings**

To supplement the classroom and lab activities, the GTS created a course reader with both science/engineering and social science/humanities resources relating to each of the four technologies and the big picture question. The intent of the reader was to prepare students to participate in class discussions and activities and to provide them with information from multiple disciplines and perspectives. The reader included science articles aimed at a general audience from the *HowStuffWorks*<sup>8</sup> website and journals and magazines such as *Scientific American* and

*Popular Science*, among others. For example, to prepare for the class on batteries and electric cars, students were assigned a reading on emerging battery technologies from *The Economist*<sup>9</sup>.

The reader also included primary source information in the form of news articles, both historical and current. Examples include the article "Injuries from Cranking an Automobile" from a 1911 edition of the *The Virginia Law Register*<sup>10</sup>, which provided a first-hand account of the safety concerns about early automobiles, and a January 2008 article entitled "The Car of the Future is Here" from *Salon.com*<sup>11</sup>, which surveyed emerging green car technologies. The reader also contained excerpts from history, philosophy, and sociology texts such as an historical overview of the rise and fall of the electric car in the early 1900s<sup>12</sup> and a journal article on the American obsession with cars in the 1950s<sup>13</sup>.

In addition to the reader, students were required to read the 1975 novel *Ecotopia: The Notebooks and Reports of William Weston* by Ernest Callenbach<sup>14</sup>. The novel presents a fictional futuristic society that is based on sustainable technologies along with the societal impacts of those decisions. It also afforded the opportunity to consider how environmental issues were presented in the 1970s after the resurgence of the environmental movement in the United States following the first Earth Day, and the 1973 oil crisis. The class analyzed the book in depth both in class discussions and as the basis for a final paper (see assessment section below)

### **4. Assessment**

The GTS were responsible for determining the assessment policy for the course. The policy was designed with several considerations in mind: (1) balance the weight of individual and group work (2) vary the types of assignments so that there was a mix of written and oral work and in class and take home work, and (3) incorporate both science-based and social science-based activities in the grading policy as



well as assignments that required students to integrate ideas from science, technology, and society. These considerations are derived directly from the key learning objectives (Figure 3). The course assessment breakdown is shown in Table 1.

As class discussions were a major focus of the course, it was important for students to prepare



Figure 3. Battery Laboratory Activity. Images of the lemon battery (top), the aluminum air battery (middle) and the basic electric motor constructed in the lab (bottom).

Table 1. Course Assessment Breakdown

| Assessment Mode             | Grade Percentage |
|-----------------------------|------------------|
| Participation               | 25%              |
| Class Contributions         | 15%              |
| Quizzes                     | 10%              |
| Written Lab Reports         | 25%              |
| Final Term Paper            | 20%              |
| Green Car Show Presentation | 10%              |
| Debate                      | 20%              |

for class by doing the assigned readings. To encourage this preparation, 10% of the course grade was based on four short, closed book quizzes, three of which were announced, and one which was a pop-quiz. The quizzes only required recall of important points from the readings. Additionally, 15% of the course grade was based on class contributions, which included asking questions, taking part in class discussions and activities, and contributing to group work in the labs.

25% of the course grade was based on written lab reports. The format of these reports varied depending on the particular lab activity. Some reports were more science-based, as in the case of the battery lab. Other reports involved social science activities; for example, one lab report entailed a survey of public opinion about the technologies studied in class. Students were required to survey their peers and to document and analyze the survey results.

A unique feature of the course was the inclusion of a term paper, which made up 20% of the course grade. The paper was based on the novel *Ecotopia*. The students were given a choice of topics, each relating to the big picture question: What factors determine the success of green technologies? For the paper, the students were asked to compare and contrast aspects of the sustainable technologies and societal impacts in the *Ecotopian* society versus American technologies and society. While this assignment was not technical writing, it required students to draw from the technical aspects of what they had learned and integrate

these aspects with social, cultural, and political factors.

In place of a final exam, the students participated in a team-based debate using a variation of the Australia-Asia debating format. The debate propositions were

1. Significant and lasting change in sustainability practices can only be brought about by government mandate.
2. The development of new technologies is necessary for the U.S. to achieve sustainability.
3. Developed nations should be held to a higher standard of sustainability than developing nations.

Students were given two weeks to prepare outside of class, and they were expected to develop arguments not just from what they had learned in class, but also to find additional resources. The teams were told which proposition they would be arguing, but they were not told whether they would argue the affirmative or negative side until just before the debate. Therefore, the students had to research and understand both sides of the debate issue. In the debate, every team member was required to speak, alternating between a speaker from the affirmative team and a speaker from the negative team. All students and GTS attended the debates and selected winners. The debate grades counted for 20% of the final grade and were determined based on input from the students, GTS instructors and MT.

## EVALUATION

### Class Composition

The Green Works course was offered to undergraduate students at UCSB in Spring 2008 and had no prerequisites for registration. Due to the novel nature of the course and the fact that it was being offered for the first time, the course was aggressively publicized in a multi-pronged strategy. This strategy included: visits to many large undergraduate classes in Winter 2008 by the GTS to advertise the course,

advertisements through undergraduate advisors of multiple departments on campus, and an advertisement in the freshman dormitory newsletter. Seventeen students enrolled in the course. Since one of the goals of the course was to increase technological literacy among non-STEM undergraduates and increase the understanding of the societal impacts of the research for students in STEM disciplines, it was gratifying to the INSCITES team that the enrolled students came almost equally from STEM and social science/humanities backgrounds. The composition of the INSCITES Spring 2008 class is listed below in Table 2.

Table 2. Class composition of students in Green Works

| Class Composition (out of 17) |                           | # |
|-------------------------------|---------------------------|---|
| Gender                        |                           |   |
|                               | Male                      | 3 |
|                               | Female                    | 1 |
| 4                             |                           |   |
| Major Discipline              |                           |   |
|                               | Science/Engineering       | 7 |
|                               | Humanities/Social Science | 8 |
|                               | Dual Major                | 1 |
|                               | Undeclared                | 1 |
| College Standing              |                           |   |
|                               | Freshman                  | 8 |
|                               | Sophomore                 | 4 |
|                               | Junior                    | 1 |
|                               | Senior                    | 4 |

### Content Evaluation

The GTS and MT decided it was crucial to survey the undergraduate students to evaluate the effectiveness of the Green Works course in particular, and the INSCITES model in general. Besides the standard University Course and Instructor Evaluations, which are required for all courses offered at UCSB, the students were given a more targeted evaluation survey specific to the unique nature of the INSCITES class. The responses detailed an overwhelm-

ingly positive reaction, as shown below in the representative comments from a selected question.

*List three things you really liked about the course.*

- Great open discussions in class, along with small class sizes; a variety of topics covering technology and society; food in class
- Small class size; three instructors; the topic
- The insight into what could be done to improve things; Ecotopian perspective; the comfortable nature of the class (small class w/ discussions)
- Discussion always allowed; notes & readings online; multiple instructors for multiple perspectives
- Interesting topics; very informal; very hands-on
- Guest lectures were informative; The format of this class was such that if you were engaged, completed your assignments, and did the readings then you would do well. It encouraged participation; Working in groups on a wide array of problems, reports, field trips to get things done.
- Eclectic subjects - solar, wind, LEDs, batteries, etc.; working outside for some labs; Guest lectures
- Relevance to today and beyond; class social atmosphere (small class size); youthful energy

In addition, our evaluation shows that there was high level of student engagement in the class (see Figure 4). When asked if they would recommend this class to a friend, all said yes or maybe. When we asked how often the students discussed this class with people other than their classmates or instructors all responded Very Often or Sometimes.

We were interested to see if taking this class made students more likely to take another class outside of their discipline. Interestingly, students who were social science/humanities majors were more likely to express this willingness than science/engineering students.

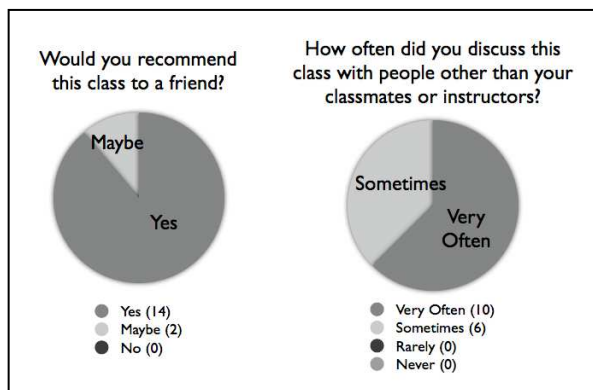


Figure 4. Evaluation shows high level of student engagement (out of 16 responders)

Of the social science/humanities majors, 5 out of the 6 responders said the class made them more willing to take a science/engineering course, while 1 said no. Of the science/engineering students, 4 out of 9 said they were more willing to take a social science/humanities course.

## DISCUSSION

The goal of the INSCITES project was to develop a series of intensely interdisciplinary courses that explores the intricate relationship between technology and society. We believe that a major component of the success of these courses is that the interdisciplinary nature was the focus on course development from the ground up. The design and implementation of such a course requires considerable time and effort as well as a willingness on the part of the instructors to learn material and teaching methods beyond their disciplinary comfort zones. Through the NSF-funded INSCITES program, we had the benefit of selecting graduate student instructors from multiple disciplines who had the passion, commitment, expertise, and curiosity to develop courses according to the INSCITES model. We provided half-time fellowships for the GTS, which meant they were able to devote a considerable amount of time to course design, averaging about 10 hours a week for two quarters to prepare the course and about 20

hours a week for the quarter that they taught the course. This time advantage is in contrast to the time constraints that most faculty face when designing a new course. An additional benefit of the GTS program is that the graduate students gained valuable experience in curriculum design and innovative teaching methods, which is quite unusual since the teaching experience of most graduate students in science/engineering disciplines is relegated to service as a teaching assistant. In this way, the INSCITES program was training the next generation of faculty who will hopefully continue to innovate and design novel interdisciplinary courses in their future careers.

While we realize that it may not be possible to recreate the INSCITES experience exactly, we think there are several aspects that can be incorporated into interdisciplinary course development. First, to create truly interdisciplinary courses, it is important to start with a team of instructors from multiple disciplines with diverse expertise. In our case we had three graduate students and four mentors, but certainly the objective can be accomplished with fewer participants. The responsibility of the team of instructors should be to collaboratively design the course with all instructors contributing to the content of each class meeting. If each instructor commits to attending each class meeting, that alone goes a long way to assuring the interdisciplinary nature of the class, even if the instructors are unable to completely design the class from scratch and are relying on material used in other courses.

Targeting a general undergraduate audience, with no specifications as to major or prerequisites makes determining a content focus for an undergraduate course especially important for student engagement. Making this decision from the beginning, so the course development can proceed from the ground up encourages and mandates the exploration and incorporation of different ways of teaching in order to best influence the particular audience for whom you are crafting the course. Structuring a course around a single topic

focuses the students and motivates their learning. This is especially true for students in a general education class who might be uncomfortable with some of the more advanced science and math concepts. Having a clear technology focus topic allows students to immediately see the application of the scientific concepts and hopefully keeps them interested and motivated to master the material. Additionally, a well-defined and manageable technological focus is important, and allows one to venture out more widely into related issues of economics, legislation, policy, history, etc. However, even a single technological focus comprises a tremendous range of science and engineering concepts. For example, consider the Green Works course with addressed solar technologies, batteries, lighting, and hybrid vehicles.

Another unique aspect of the program was the low student to instructor ratio in each of the courses. In the Green Works class, there were three instructors and 17 undergraduate students, which represents a student/instructor ratio of about 6-to-1. At a large research institution such as UCSB, it is uncommon for freshman students to have this kind of access to instructors. The small class size also enabled the instructors to incorporate more alternative modes of instruction such as mini-debates, small group discussions, brainstorming sessions, group problem-solving activities, think-pair-share activities, etc.

These kinds of integrated courses have the potential to attract new students into STEM. As mentioned in the evaluation section, the majority of social/science humanities students (5 out of 6) responded that they were more likely to take a science/engineering course after completing the Green Works INSCITES course. We have been interested in expanding the reach of the INSCITES program and have recently secured funding for a pilot project to introduce these courses into our local community college. Targeting community colleges allows us to engage students before the stage where they must declare a major when transferring to a 4-year university. Given the

high percentage of underrepresented students in the California community college sector, it will also engage substantial numbers of talented students who currently do not choose to pursue further courses, and careers, in science and engineering.

## CONCLUSION

In a society in which technology is intertwined with nearly every aspect of our lives, it is imperative that all students achieve a basic level of scientific and engineering literacy. The integration of scientific and technological concepts into general education courses is a crucial step toward achieving this goal. We describe a novel approach to general education course design in which science and technology are taught in conjunction with the societal, historic, economic and political context. Under the umbrella of the INSCITES project, three topic-specific, interdisciplinary courses were designed and implemented according to this model. We have described the course development model in detail and outlined the course implementation for one specific course focusing on green technologies. As evidenced by student evaluation, the courses were successful in engaging both science/engineering and social science/humanities students.

## ACKNOWLEDGEMENTS

The INSCITES project was funded by the NSF under grant 0525271. Any views expressed in this paper are the sole responsibilities of the authors and are not necessarily endorsed by the NSF. The authors would like to thank the following people for their contributions to the development and implementation of the INSCITES courses as graduate teaching scholars: Jose Anguiano, Lindsay Gary, Erin Lennon, Neda Maghbouleh, Hussam Mousa, Keely Roth, Stacy Patterson, and Ridah Sabouni. The authors also wish to thank the students for participating in these novel course offerings and for providing useful feedback.

More information about the INSCITES program and courses can be found at: <http://balzac.cnsi.ucsb.edu/inscites/> or by e-mailing [murr@cnsi.ucsb.edu](mailto:murr@cnsi.ucsb.edu)

## REFERENCES

1. *Science and Engineering Indicators*, National Science Board, 2004.
2. S.A. Jackson, SA. 'The Quest Crisis: Falling Short in Producing American Scientific and Technical Talent' (2004). [http://www.rpi.edu/homepage/quietcrisis/quiet\\_Crisis.pdf](http://www.rpi.edu/homepage/quietcrisis/quiet_Crisis.pdf).
3. N.R. Augustine, *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. National Academy Press, Washington, DC, 2005.
4. <http://www.nsf.gov/pubs/2004/nsf04594/nsf04594.htm>
5. A.H. Johnstone, "Attention Breaks in Lectures", *Education in Chemistry*, **13**(2), 49 (1976).
6. <http://pbskidschannel.org/zoom/activities/sc/ilemonbattery.html>
7. Modesto Tamez and Julie H. Yu, "Aluminum - Air Battery", *J. Chem. Educ.* **84**, 1936A (2007).
8. <http://www.howstuffworks.com>, accessed August 14, 2009.
9. "In Search of the Perfect Battery", *The Economist*, March 6, 2008.
10. "Injuries from Cranking an Automobile", *The Virginia Law Register*, **16**, No. 12, 956-957 (April 1911).
11. Joseph Romm, "The Car of the Future is Here", *Salon.com*, January 22, 2008.
12. David A. Kirsch, "Industrial Ecology and the Future of the Automobile: Large-Scale Technological Systems, Technological Choice, and Public Policy" from *The Electric Vehicle and the Burden of History*, Rutgers University Press, 2000. pp 232 – 237.

13. Karal Ann Marling, "America's Love Affair with the Automobile in the Television Age", *Design Quarterly*, No. 146, *Autoeroticism*, (1989), pp. 5-20.
14. Ernest Callenbach, *Ecotopia: The Notebooks and Reports of William Weston*, Banyan Tree Books, Berkeley, California, 1975.