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The creation of an integrated sustainability curriculum and student praxis projects

Christopher M. Bacon, Dustin Mulvaney, Tamara B. Ball, E. Melanie DuPuis, Stephen R. Gliessman, Ronnie D. Lipschutz and Ali Shakouri

(Author affiliations can be found at the end of the article.)

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Abstract

Purpose – The purpose of this paper is to share the content and early results from an interdisciplinary sustainability curriculum that integrates theory and practice (praxis). The curriculum links new topical courses concerning renewable energy, food, water, engineering and social change with specialized labs that enhance technological and social-institutional sustainability literacy and build team-based project collaboration skills.

Design/methodology/approach – In responses to dynamic interest emerging from university students and society, scholars from Environmental Studies, Engineering, Sociology, Education and Politics Departments united to create this curriculum. New courses and labs were designed and pre-existing courses were "radically retrofitted" and more tightly integrated through co-instruction and content. The co-authors discuss the background and collaborative processes that led to the emergence of this curriculum and describe the pedagogy and results associated with the student projects.

Findings – Interdisciplinary student teams developed innovative projects with both campus and community-based partners. However, the incentives for an integrated sustainability curriculum faced persistent obstacles including the balkanization of academic knowledge, university organizational structure, and the need for additional human and financial investments. The team is currently designing the second phase of this integration and expanding a social learning network through collaborations with five universities in the Americas and Europe.

Originality/value – This paper shows the development process, design and content of an interdisciplinary sustainability curriculum that integrates engineering with the social and ecological sciences while enlivening campus-community relationships through student projects. Several replicable practices include the contents and integration of topical classes, the strategies to overcome the obstacles for developing interdisciplinary student teams engaged in problem-based learning and approaches to negotiate institutional hurdles.

Keywords United States of America, Universities, Curricula, Problem based learning, Sustainable development, Innovation

Paper type Case study

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1. Introduction

Although many obstacles persist there is a vibrant greening trend in higher education as teaching and research agendas look to incorporate the goals of sustainability and development (Barlett and Chase, 2004; Wynn and Dautremont-Smith, 2009). Since 1990 campus-based sustainability oriented initiatives and collaborative pledges ranging from the Talloires Declaration of Universities Presidents for a Sustainable Future to United Nations' "Decade of Education for Sustainable Development" have underscored the merits sustainability education, research, and outreach (Garcia *et al.*, 2006; Filho, 2000). Institutions of higher learning are often at the forefront of climate action plans, sustainability research, and private-public collaborations, alongside pedagogical shifts toward sustainability literacy (Ollis and Krupczak, 2007). Despite these efforts, broader educational trends have emerged as persistent obstacles slowing campus greening, and possibly stifling innovation (Haigh, 2005). These trends include:

- increasing specialization into narrowly defined academic disciplines, which separate science, technology, engineering, and mathematics disciplines from those that emphasize human-environmental interactions;
- departmental and other institutional barriers to collaboration amongst faculty and amongst students; and
- ivory-tower teaching traditions that externalize the outside world are hindering scientific literacy (Barlett and Chase, 2004; Godemann, 2008; Warburton, 2003).

Initial university responses to the call for sustainability on campus have varied widely as some pioneer institutions respond with broad-based proposals for change in operations, research, planning, and curricula, while many others have thus far failed to move beyond declarations and collectively promoting their currently departmentalized activities (e.g. courses, research centers, projects) related to environmental sustainability (Ryan *et al.*, 2010; Geli de Ciurana and Filho, 2006). Conventional instructional approaches, centered on didactic lecture-lab models that treat knowledge as information, engage students as passive recipients, and focus on individual learning, persist within higher education (Sharp, 2002).

A growing interest in "sustainability science and engineering" (Brand and Karvonen, 2007) and a more democratic education (Dewey, 1903) suggests the need for transdisciplinary collaborative solutions that integrate sustainability education across diverse curricula (Komiyama and Takeuchi, 2006; Savin-Baden, 2000). The complexity of real-world sustainability challenges (Orr, 2002) and desires to train students for the emerging green workforce both suggest the need for developing core competencies and innovative educational practices.

A holistic framework encourages students to look for solutions in the social, cultural, ecological, and political spheres of life (Stephens, *et al.*, 2008). This requires an integrated approach to carefully examining social and environmental needs, in contrast to narrowly defined solutions in search of problems (Ashford, 2002). Some problems require innovations in engineering, while others suggest social innovations and/or changes to daily routines. For example, technical aspects of energy production are questions for engineers, while the habits of lifestyle and consumption are largely for social scientists. But designing and deploying a sustainable energy system is largely one where both will need to work together. The same could be said for conservation, given the need to dramatically reduce the lifestyle impacts of many Northern consumers, transform unsustainable social norms, and develop strategies to address growing social inequalities (Seyfang and Smith, 2007).

This paper will highlight the experiences university-based actions to change from within to more effectively fulfill higher education's role in facilitating the transition toward sustainable societies (Ferrer-Balas, *et al.*, 2008). The purpose of this article is to share the first phase results from an approach to an interdisciplinary sustainability curriculum that emphasizes interaction, reflexivity and the integration of theory and practice (praxis) (DuPuis and Goodman, 2005). The curriculum links topical courses concerning renewable energy, food, water, engineering and social change with specialized labs that enhance technological and social-institutional sustainability literacy and build team-based project collaboration skills. The next section provides a short review of previous experiences with sustainability science curricula and project-based learning clarifying definitions and highlighting opportunities and challenges. Sections three and four share the results of the University of California, Santa Cruz (UCSC) experience and then discussion lessons learned.

2. Sustainability science curriculum and project-based learning

"Sustainability science" can be broadly described as the "science that sets standards for the transition to sustainability while developing indicators for the process" (Clark and Dickson, 2003; National Research Council, 1999). It involves the interdisciplinary integration of knowledge, insights, skills and practices from the natural and social sciences and engineering directed toward contemporary and long-term protection and well-being of the Earth, its environment and its non-human and human inhabitants. Some suggest making sustainability science and engineering a new metadiscipline to integrate the environment, society, and industrial systems (Mihelcic, *et al.*, 2003). This argument points to the limitations of "end-of-pipe" thinking, and suggests sustainability oriented students require a different set of skills and that include:

> (i) fundamental physical sciences, social sciences, and math needed for environmental assessment and engineering; (ii) basic economics including input-output analysis; (iii) industrial ecology and design at the process, plant, corporate, regional, national, and global scales; (iv) information technologies for real time monitoring of processes, remote sensing of the environment, and graphical information systems; (v) human and environmental impact modeling and risk assessment; (vi) social and behavioral research tools; (vii) understanding sustainability issues in a global context, with emphasis on the developing world; and (viii) professional and K-through-12 educational programs.

The tremendous opportunity in calls for interdisciplinary collaborations and sustainability education is the possibility of a collective response producing still unknown green innovations. In contrast to the incremental innovations associated with ecological modernization (Mol and Spaargaren, 2000), a focus on sustainability science and project based learning requires the interdisciplinary synthesis of concepts and praxis, which is more likely to generate the radical or disruptive technologies that substantially improve efficiencies and equities shifting systems of production, provision and consumption and opening new possibilities (Metzger and Zare, 1999). Dynamic team-oriented students trained in interdisciplinary collaboration are more likely to include user perspectives and integrate both social and ecological concerns into the engineering and design process upfront instead of *ex-post facto*. Campus partnerships with community-based enterprises in addition to local governments and firms could also contribute to valuable grassroots innovations (Seyfang and Smith, 2007). The goals of incorporating sustainability education into engineering curriculum also meet some of the aims of programs aimed at broadly introducing ethics into engineering curricula (Herkert, 2000).

Several challenges accompany efforts to implement interdisciplinary curriculum. Ashford (2004) identifies obstacles to incorporating sustainability concepts into engineering education, including the existing workload encountered by engineering students and an apparent reluctance study normative issues. Alternatively, students with a social sciences background may be disinclined or lack the confidence and experience to readily engage in quantitative reasoning. More generally, there are challenges associated with implementing collaborative learning designs among students who identify with different disciplines. The social psychological challenges of teamwork (e.g. communications, expectations, roles, gender, and power dynamics) can be exacerbated by competing epistemologies (Godemann, 2008).

Behind pedagogic challenges of integrating curriculum are the intellectual and practical obstacles to interdisciplinary and transdisciplinary scholarship (Petersen, *et al.*, 2007). These efforts are frequently hindered by cultural and epistemological divisions between the natural and social sciences, institutional and incentive structures that prioritize specialization, and reflect the historical momentum of a segmented university-based knowledge system (Soule and Press, 1998). The disciplinary norms of instructors may differ from the pedagogical task of integrating content across disciplines, or it may reduce the problem in such a way that misses important dimensions. For instance, a disciplinary approach to sustainability education highlight the planet's larger bio-geo-chemical cycles and trends, but fall short of describing the roles and impacts of human society, culture, and livelihoods. This is a point made by Orr (2002) when he argues with (Odum and Odum, 2001) that curricula need to be reoriented to understand the relationships between energy, environment, and society to provide long run intellectual leadership. The segregation of disciplines also creates a mismatch between the production of academic knowledge and the need to respond to the pressing environmental and social problems (Godemann, 2008). Eliminating these discrete centers of knowledge production requires deliberate efforts to create more holistic, integrated, collaborative problem-oriented approaches.

Project-based learning can provide students with real-world applications to spur their interdisciplinary training (Boud and Feletti, 1997). These projects can generate opportunities for universities and community-based partners, contribute directly to campus sustainability through applied projects (Sharp, 2002), introduce students to sustainability thinking, and influence social practices (Cortese, 2003).

Another aspect of team-based learning is found in the literature on active/collaborative learning (Chau, 2007). The elements that characterize the goals of these approaches are positive interdependence, individual accountability, group processing, social skills, and face-to-face interaction (Rosca, 2005). Harrison *et al.* (2007) share the results from an interdisciplinary hands-on design course that resulted in student-led plans to design and deploy a hydropower project on campus. Their findings focused on several important gains from such collaborations, including:

- appreciation of other engineering disciplines;
- experience in teams of different skills and expertise;

- links between engineering design and economic viability;
- development of non-technical areas of competence; and
- developed interest in specific topics.

3. Sustainability education, engineering and ecological design at UCSC

The following two sections introduce the starting points, curricular proposal, and the results associated with Sustainability Engineering and Ecological Design (SEED) at the UCSC. After a long history of environmental work, two the National Science Foundation (NSF) recently funded two curricular proposals. The first project, titled "Renewable Energy and Engaged Interdisciplinary Learning for Sustainability (REELS)," was submitted through the School of Engineering and the second complementary proposal, titled Sustainability Engineering and Ecological Design-Learning Partnership (SEED-LP), was sent through the Division of Social Sciences.

In many respects, UCSC is an ideal setting to launch a sustainability curriculum. This mid-sized public collegiate university serves 15,000 students and is known for commitments to cross-disciplinary undergraduate education, innovative teaching methods, and its stunning rural campus. The regional expertise available for possible partnership includes the Silicon Valley clean tech sector, Bay Area foundations, several government renewable energy and energy efficiency labs, and environmental organizations, and a cluster of organic farms and sustainable agri-food enterprises.

UCSC also has a history of student activism around environmental and social justice issues. Different individuals, centers, and departments within the university maintain multiple campus-communities ties across a broad range of issues ranging from new teacher training to social justice and new business innovation.

Inspired by The Earth Charter (ECI, 2000), fellow students, and a host of environmental leaders, a core group of undergraduate student activists and faculty mentors helped launch a Student Environmental Center in (2001) and Campus Sustainability Council (2003) that organized multiple campus Earth Days, the Education for Sustainable Living Program (2003), which created a series of for student-led courses, and the College 8 Sustainability Project. Two other important programs that emerged were the Program in Community and Agriculture (2002) and the Community Agroecology Network (2002). The former is a residential living-learning community and the latter provides a campus-based non-profit organization connected to five Mesoamerican-based communities through intercultural exchange, community-based participatory action research and fair trade direct coffee.

Since its founding in 1965, UCSC faculty have engaged in environmental scholarship from departments such as Sociology, Anthropology, Politics, and Environmental Studies (founded in 1972), as well as centers such as the Center for Agroecology and Sustainable Food Systems. While the Environmental Studies Department and environmental specializations in sociology and politics have thrived, UCSC had never developed a series of courses leading towards an integrated campus-wide sustainability curriculum. This project was initiated to respond to that gap.

4. Project overview and findings

The REELS project aims to foster interdisciplinary collaboration between engineering and the social sciences through new course development, improved project-based learning opportunities and laboratory practice. Campus-community partnership will be invigorated as action-based interdisciplinary student teams begin their work. The objectives are to increase the scientific and technical literacy of social science and humanities majors, while exposing engineering and natural science majors to social diversity, inequality, and environmental justice into the core components of sustainability engineering.

Figure 1 is a conceptual schematic for our plan to create new courses, laboratories and form links among them. It involves a gateway course on topics in sustainable engineering and practice that prepares students to enroll in more advanced courses organized around three themes: renewable energy sources, water resources, and agrifood systems. Each of these courses will integrate:

- a social justice component tailored to the demands associated with a specific theme with;
- quantitative analysis; and
- Hands-on laboratories that emphasize the development of science-inquiry and engineering-design process skills.

In addition, community/industry projects and case studies will bring real life examples and connect course materials. Advanced multiyear and interdisciplinary student projects can lead to capstone senior design projects and/or internships. These courses compose an integrated curriculum known as SEED, which is evolving into a certificate program.

The gateway course is a topical introduction to principles and practices of SEED defined as the planning, development and deployment of technological and social

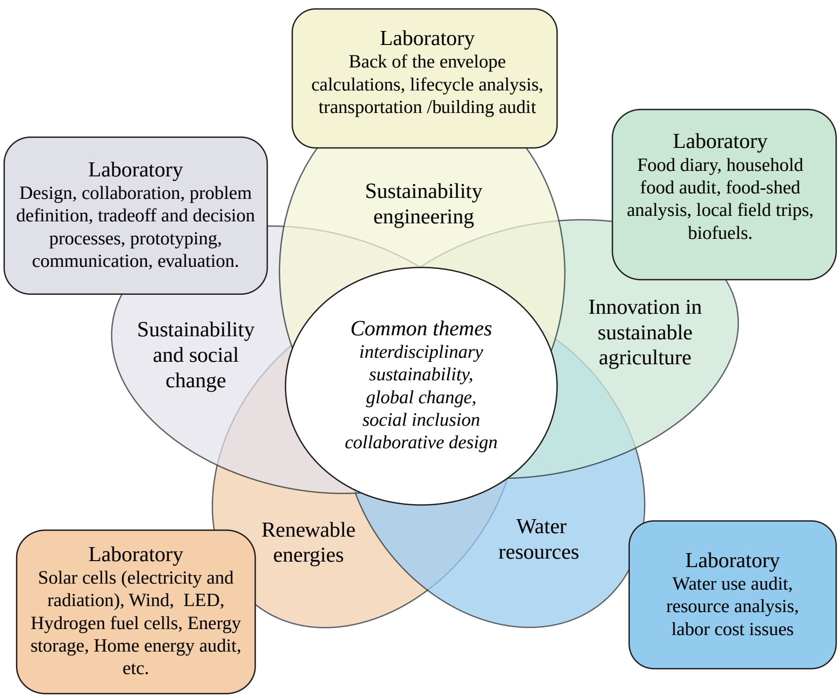

Figure 1.
Sustainability curriculum proposal

systems and institutions that can protect the earth's ecological systems for this and future generations. No specialized background in engineering, natural sciences or social sciences is required, and the course is open to all students.

A second course called Sources of Renewable Energy introduces concepts in energy conversion and storage. It focuses on fundamental energy conversion limits based on physics and existing material properties and various renewable energy sources such as solar, wind, hydropower, geothermal and biofuels, as well as energy storage technologies such as batteries and fuel cells. Drawing on the electrical engineering department's expertise in solar cell, waste energy harvesting, and nanotechnology research, the course introduces sources of renewable energy and identifies key scientific, economic and social roadblocks for large-scale implementation.

A third course, Collaborative Design for Sustainable Technology, focuses on the collaborative nature of problem-based projects that involve a wide variety of backgrounds. Students in this course have some experience in technology, technical design, project design or collaboration processes and either:

- have formulated projects that they will pursue through this lab; or
- join with existing project collaborations that have begun in other courses.

Students work with each other to improve collaborative skills and to further design their projects. Labs both build skills through workshop type exercises, discussion of readings, team project work, and active learning processes that provide a background to processes of collaborative interactions.

Technological and social-institutional literacy

Dovetailing with this initiative is the SEED-LP funded by the US NSF and initiated to enhance the REELS project. The project is motivated by two elements:

(1) specialized courses in technological and social-institutional sustainability literacy; and

(2) "hands-on" applied sustainability labs where students work as teams in partnership with agencies, organizations, and businesses engaged in sustainability questions, policies, and technologies.

The specialized course on technological literacy focuses on the "back of the envelope" calculations, making social science students more comfortable with and skilled in basic understandings of the biophysical dimensions of human consumption through life cycle analysis. The specialized social-institutional literacy course focuses on the analytical strengths of the social science methods to evaluate decision-making processes, the role of technologies in institutions and social relationships, policy studies, and social innovations.

The creation and piloting of the "hands-on" labs at the Program in Community and Agroecology (PICA) and its sustainable living center (SLC) has given the students opportunities to learn about renewable energy generation such as solar thermal hot water, ethanol production from grape wastes, and biogas production from manure; as well as opportunities to conduct site assessments and energy audits. These courses provide students with basic sustainability problem solving approaches and offer project-based learning opportunities in the sustainability context.

Community and campus based student sustainability projects

Student projects are a keystone to an integrated sustainability curriculum. To locate potential projects, a post-doctoral course manager met with potential mentors, including municipal government agencies (e.g. water and economic redevelopment), campus-based units (e.g. climate change coordinator, sustainability coordinator, physical plant, and the planning department), and local non-profit organizations (e.g. economic development, environmental oriented, and social service providers). Mentors were asked to commit to two in-person meetings with student teams and were promised a copy of their final project and the possibility of establishing a longer-term partnership.

To enable communication and build project support, an annual evening presentation was conducted with potential mentors. The partners, 15-20 people ranging local business leaders, the city mayor, and non-profit directors, provided initial ideas for potentially useful student projects. These contacts became the basis for a database of mentors and project ideas, which is continually updated with new mentors, project ideas, and progress on existing projects.

The five unit courses include three-and-a-half hours of lecture and 70 minutes of discussion section per week. The goals of the sustainability projects were introduced during the first class of the quarter, and the first section was dedicated to facilitating group organization and facilitating project ideas. In the first section meeting, a brainstorming session was initiated by the project coordinator. During this session the focus was a discussion about unsustainable practices on the campus. As students identified problems and solutions, students were invited to suggest specific projects. Ideas were listed on the blackboard and students were asked to vote for projects they would be interested in pursuing. The same process was followed in a subsequent class and more detailed project ideas began to emerge as students became attached to certain ideas. Students who contributed ideas became team leaders, and other students were asked to select a project to work on. Effort was made to ensure that each group represented a diversity of majors and skill sets, although this was not always possible because of the uneven distribution of majors in the sections and it was decided that students should work on projects of their choice.

Student teams were given guidelines for dividing the teamwork amongst themselves. The division of labor included assigning one student to be the primary contact with the project coordinator, though all students were invited to meet with the coordinator at any time after class or during office hours. Other tasks included data collection, interpretation, report editing, and literature collection. By the fourth week students were asked to submit a prospectus that the course coordinator could approve. Once approved, student groups were assigned mentors where there was an appropriate match from the database, or where someone from the database would be helpful in student advisement (mentors were asked if they would be available to help on projects that did not specifically fit their project description). The following summaries offer examples of three dynamic projects.

A solar municipality utility in Santa Cruz, California. One student project grew from the Renewable Energy (EE80J) course emerging from prior conversations with the city redevelopment agency and a local environmental NGO's climate change program coordinator. The interdisciplinary student team spanned the social sciences and engineering disciplines. The team proposed rooftop solar panels in downtown Santa Cruz. After reviewing analogous projects, the team conducted stakeholder interviews, gathered data, and made calculations. The team developed spreadsheets estimating roof areas using Google Earth©, solar photovoltaic energy production potential, costs and savings. Each downtown business owner could evaluate the solar energy costs and benefits and the city could evaluate the feasibility of a municipal solar utility. Finally, they compiled findings into an informative pamphlet. The project received widespread positive responses from community-based partners and groups have worked to create follow-up projects.

Student-led bike course and cooperative. The idea for the student bike lending cooperative and a self-directed course percolated up from within the student body. This specific project emerged from the Sustainability Engineering and Practices course (EE80S). One engineering student, served as the overall coordinator for this group that involved nine students with majors ranging from engineering and environmental studies to psychology and economics. She traced the initial idea to her previous involvement in the Super Rad Bike Club (SRBC) the previous spring. To reduce air pollution, greenhouse gas emissions, and traffic on campus, this project aims to increase bike ridership through a comprehensive bike course and cooperative-based bike library. The course is directed towards students who would otherwise not be biking. Students taking the course will gain a holistic understanding of bicycles through lectures, labs, and a community project. The group later allied with the Student Environmental Center to find funding for the project and identified an engaged faculty sponsor. After completing EE80S, several student leaders taught this course through the Education for Sustainable Living Program (available at: http://eslp.enviroslug.org/), which is series of student led, faculty mentored, university accredited courses.

Wastebin workshop. A group of students in the EE80S course proposed a project to implement a recycled art collective in the SC community. The "wastebin co-op" idea would supply artists with recycled materials while diverting waste from municipal landfills. A single student leader continued to build on the idea and enroll other students in the project, as several students contributed complimentary ideas, justifying the project on the grounds of ecological and life cycle thinking in waste utilization. The course coordinator previously established communication with a local non-profit called Grey Bears Recycling that operates a job creation program and recycling facility. Students approached Grey Bears about how to set a recycled art collective into motion. The project mentor at Grey Bears enthusiastically endorsed this project. After several trips to the recycling facility, the students listed recoverable materials, designed alternative collection sites and sorting logistics, and estimated the potential tonnage that could be diverted from local landfills. The estimate of waste diversion fulfilled the project requirement of making "back of the envelope" calculations (Table I).

Student assessments and instructor response

Students and our own self-assessments assessments were gathered through ongoing conversations among participating instructors, student surveys conducted midway and at the conclusion of each course, and two focus groups with previous students (conducted in Summer 2009). The results show high student demand, perceptions of improved knowledge, and reports of changed behavior. From 2006 to 2009, these keystone courses on Renewable Energy and Sustainability Engineering were taught nine times to 950 students. Enrolled students came from a diversity of engineering and social science majors and more than 80 percent claimed to have advanced their knowledge in most of the core thematic areas (e.g. solar cells, agroecology, and sustainable agriculture).

	Partner/mentor
Heating the campus swimming pool with solar thermal	Campus energy manager
Feasibility of producing biodiesel from campus vegetable oil sources	Faculty
Solar photovoltaic on campus parking lots	Campus climate council
Expanding composting in campus dining halls and dorms	Campus recycling coordinator
Increasing campus bike accessibility and safety	Transportation director
Fog and rainwater collection on campus buildings	Faculty
Energy metering in campus dorms to increase awareness of energy use	Housing resource conservation coordinator
Implementing wind power at the UCSC Lick Observatory	Campus climate council
Thermoelectric converter installation on SC boardwalk	SC Boardwalk
Solar power Ferris wheel with regenerative braking	SC Boardwalk
Expanding campus Homegardens	Faculty
Energy efficiency at UCSC computer labs	Faculty
Wastebin workshop recycled art collective	Grey Bears recycling

Table I.
Examples student-team projects

More than 60 percent claimed they changed behaviors toward more sustainable ones (survey results EE80S fall 2008). Students reported that the diversity of topics and guest lectures and faculty co-instruction was effective. They gave especially high ratings to teaching assistants and readers for their contribution to student learning.

In early feedback, students suggested reforms to the Sustainability Engineering course and highlighted the difficulties of group work coupled with time constrains and the high expectations associated with the projects. The authors responded by developing the aforementioned protocol for group work, a peer-based grading framework, and a set of interconnected assignments that start during the first week of the course.

5. Discussion and implications

After three years implementing this curriculum gives rise to several questions: what approaches were the most effective strategies to develop problem-centered learning and student projects together with an integrated sustainability curriculum? What were the challenges and how did this collaborative respond? How does this experience compare with other higher education efforts to green the curriculum? What are lessons learned to date and which unanswered questions persist?

Student sustainability praxis projects, assessment and next steps

The results confirm that interdisciplinary student projects are a useful pedagogical tool to teach students through experience (Boud and Feletti, 1997; Barron *et al.*, 1998). The project report quality can measure student ability grasp of the meaning and analysis of these concepts and tangible outcomes contribute to operational sustainability goals (Warburton, 2003). Previous projects, such as the dorm-based energy monitoring systems at Oberlin improved energy efficiency (Petersen, *et al.*, 2007). The projects reviewed above created opportunities for praxis in a short time frame and several longer-term partnerships developed (Brundiers, *et al.*, 2010). However, challenges such as funding, different community and university time frames, and need to provide faculty and/or staff (post-doctoral researchers) time to follow-up have resulted in only a few projects will be seen through the implementation stage.

One problem is related to short quarters and the lack of synchronicity with timeframes and expectations from community and campus partners, who often expect a longer-term commitment in return for their efforts. Mentors often have high expectations. This can be managed if a course manager filters projects, but this requires staff time. Faculty and post-docs have nurtured the individual relationships that sustain these partnerships and started to identify an agenda for future student teams.

One next step is the creation of the Campus Sustainability Clinic as a pilot course. This pilot course will be a year-long project development and implementation course, rather than existing SEED "project incubator" courses. The Campus Sustainability Clinic will be a venue where student ideas incubated in the initial SEED courses (Figure 1) meet sustainability needs identified by campus planning efforts.

This campus-based project-oriented course is complemented with a second strategy to strengthen campus-community collaborations and generate local and global options for student projects and international exchange courses. The PICA (http://ucscpica.org/) offers internships with several local sustainable agriculture and food system enterprises and it houses the infrastructure (e.g. solar panels, water catchment systems) for additional hands-on labs. Located in the same physical space, the Community Agroecology Network (www.canunite.org) offers intercultural education and field-based project opportunities in five rural Mesoamerican farming communities. Both organizations regularly host international short-courses organized around agroecology and sustainable food systems. This work is complemented by Professor Shakouri's international renewable energy short-courses which engage in international collaborations with European counterparts (http://localrenew.ning.com).

How does the UCSC experience compare with that of other US-based universities?

Studies of US higher education institutions identified barriers to creating sustainability curriculum that included the academic silos and scale (e.g. many universities are administered as individual vertical units, not conducive to collaboration) and the lack of incentives that support faculty and staff efforts (Barlett and Chase, 2004; Haigh, 2005). Research into project-based learning with partner communities has identified similar difficulties related to a lack of formal recognition in the tenure processes for faculty involvement in these partnerships to the meeting the expectations of some community-based partners and creating a two-way collaborative exchange (Brundiers *et al.*, 2010). In this case, these obstacles were exacerbated by tightening budgets and rising tuition, impeding investment in additional courses and curriculum development.

Although hundreds universities have adopted sustainability initiatives amply reviewed in previous studies (Brunetti *et al.*, 2003; Dautremont-Smith, 2003), for the most part – at least at US institutions of higher education – these appear to be based in engineering and science disciplines and few seek to integrate engineering and science with the social sciences to the extent proposed above. Some interesting exceptions to this include Arizona State University's (ASUs) School of Sustainability (SOS), the University of Michigan's Global Change minor, and Oberlin College's environmental studies program. Purdue University's Engineering Projects in Community Service program (EPICS), now in its 16th year, has successfully integrated engineering and social science students at the project level, and boasts many successful components that are incorporated in our work.

Several of these endeavors including those at the University of Michigan and ASU reported successfully integrating interactive projects into large classrooms settings to advance sustainability curriculum (Beichner and Saul, 2004; van der Pluijm, 2006, p. 249). A recent study at ASU focused on using "real world problem oriented projects to advance sustainability learning" found critical success factors to collaborative design, coordination, and integration into general introductory courses for undergraduate students (Brundiers *et al.*, 2010).

Ferrer-Balas *et al.* (2008) compared sustainability transitions at seven universities in several countries concluding that campus-based sustainability curriculum is enabled by:

- the presence of "connectors" people working between departments, faculty and admin campus/community, etc.;
- existence of coordinating bodies (e.g. centers, institutes, committees); and
- the availability of funding.

This endeavor benefited from the creation of a cluster of active faculty, post-docs, graduate students, and staff that serve as connecters clearly enabled the first steps in this processes. As is the case elsewhere, faculty initially undertook this effort as an "extra" task beyond their regular teaching, research, and administrative commitments. NSF funding provided a vital spark to support graduate students, post-docs, and faculty in these curricular building processes. As deans and department chairs witness the collaboration, rising enrollments, and learning outcomes additional support has started to materialize.

6. Conclusions

This paper shows the context, collaborations, design and content associated with the emergence of an interdisciplinary sustainability curriculum that integrates engineering with the social and ecological sciences while enlivening campus-community relationships through student projects. An emphasis on student-led campus and community projects is a tangible way to integrate a sustainability curriculum because students focus on local problem-solving situations. Campuses and communities can gain from student's efforts, as they contribute to sustainability councils and climate action committees, develop plans to reduce rising energy costs, and pursue green policies and practice. Yet putting students into situations to implement successful sustainability projects will require time and careful planning. Much effort is required to initiate and collect content for training students on projects, so the plan is to work with collaborators and colleges to leverage resources, personal, and ideas, and will disseminate our future findings broadly. An approach that emphasizes student-led group projects responds to the need for problem-based learning and invites collaboration and cooperation in a system that typically rewards individual learning and competition.

Several strategies and practices reviewed in this case are replicable inputs into the dynamic ongoing efforts of many individuals and organizations advancing sustainability and higher education. This case study shows the contents and integration of topical classes in SEED, strategies adopted to overcome the obstacles for developing interdisciplinary student teams engaged in problem-based learning, and efforts to negotiate institutional hurdles. The laboratories, student assessment metrics, and content developed in this project are disseminated online and available at: http://seed.soe.ucsc.edu. This includes course frameworks and lecture content, labs that seek to enrich socio-technical literacy, and guides for project development.

Most of the content, labs and experiences reviewed here is in the early stages of development and it will benefit from subsequent iterations and the insight gained from a wide diversity of active collaborators at universities ranging from two-year community colleges, masters granting universities, to other research-oriented public universities. Several active collaborators are developing similar courses, engaging in student team-based learning activities, and assessing students participating in a share suite of labs using the same metrics. Aside from UC Santa Cruz, currently active collaborators include Cabrillo College, San Jose State University, Santa Clara University, the University of Vermont, as well as partner universities involved in specific international training efforts including the Technical University of Denmark, Aalborg University and several Universities and Research Centers in Mexico and Central America including (Universidad de Chipingo, Universidad Intercultural Maya De Quintana Roo, La Universidad Nacional Autonoma de Nicaragua) and several others.

There is broad agreement concerning the need to integrate sustainability-oriented skills courses across engineering and social science departments. But pressing questions about the overall curricular goals remain unresolved. How much emphasis should be placed on developing the skills for successful job placement vs cultivating a contextual understanding of what this means and engaging notions of sustainability citizenship in a global world? An integrated sustainability curriculum avoids an either or answer as it seeks to co-create pedagogic pathways that yield effective, reflective and engaged students capable collaboration and inspired to spur the innovations vital to the transition towards more sustainable societies.

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Further reading

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Authors' affiliations

Christopher M. Bacon is based at the Environmental Studies Institute, Santa Clara University, Santa Clara, California, USA.

Dustin Mulvaney is based at the Department of Environmental Science, Policy and Management, University of California, Berkeley, California, USA.

Tamara B. Ball is based at the Institute for Scientist and Engineer Educators and Sustainable Engineering and Ecological Design, University of California at Santa Cruz, Santa Cruz, California, USA.

E. Melanie DuPuis is based at the University of California at Santa Cruz, Santa Cruz, California, USA.

Stephen R. Gliessman is based at the Program in Community and Agroecology, Department of Environmental Studies, University of California at Santa Cruz, Santa Cruz, California, USA.

Ronnie D. Lipschutz is based at the Center for Global, International and Regional Studies, University of California at Santa Cruz, Santa Cruz, California, USA.

Ali Shakouri is based at the Jack Baskin School of Engineering, University of California at Santa Cruz, Santa Cruz, California, USA.

About the authors

Christopher M. Bacon is an Assistant Professor in the Environmental Studies Institute at Santa Clara University. He received a PhD in environmental studies and subsequently worked as an instructor in the SEED project in the Department of Electrical Engineering, UC at Santa Cruz. Substantial writing for this project was conducted as a Ciriacy-Wantrup Post-doctoral Fellow in the Geography Department at the University of California, Berkeley. He is the author of several articles on participatory action research, environmental and food governance, and food security in the Americas and Co-editor of *Confronting the Coffee Crisis: Fair Trade, Sustainable Livelihoods and Ecosystems in Mexico and Central America*. Christopher M. Bacon is the corresponding author and can be contacted at: cbacon@scu.edu

Dustin Mulvaney worked as a Project Manager in the Department of Electrical Engineering, UCSC from 2008-2009. He is currently a Science, Technology, and Society Postdoctoral Scholar in the Department of Environmental Science, Policy, and Management, University of California, Berkeley.

Tamara B. Ball is a Post-doctoral Research Fellow with the Institute for Scientist & Engineer Educators and the program on Sustainable Engineering and Ecological Design at the University of California, Santa Cruz. Dr Tamara B. Ball completed a PhD with the Education Department at UCSC and conducted post-doctoral research on whether and how undergraduate research apprenticeship programs in science and engineering involve interns in scientific argumentation. Tamara B. Ball focuses on translating educational research and theory into practice.

E. Melanie DuPuis is Professor of Sociology at UCSC and Associate Academic Director of the UC Washington Program. She is the Editor of *Smoke and Mirrors: The Culture and Politics of Air Pollution* and the author of *Nature's Perfect Food: How Milk Became America's Drink*.

Stephen R. Gliessman is Ruth and Alfred Heller Professor of Agroecology in the Department of Environmental Studies at the University of California, Santa Cruz. He directs the PICA, an on-campus residential experiential learning community focused on food system sustainability. More information on his work can be found at: www.agroecology.org

Ronnie D. Lipschutz is Professor of Politics and Co-director of the Center for Global, International and Regional Studies at UC-Santa Cruz. He has been research and writing on environmental politics and policy since 1979. His most recent book is *Political Economy, Capitalism and Popular Culture* (Rowman and Littlefield, 2010), and he is Co-editor of *Global Environmental Governance – Power and Knowledge in a Local-Global World* (Routledge, 2009).

Ali Shakouri is a Professor of Electrical Engineering at University of California Santa Cruz. His current research is on nanoscale heat and current transport in semiconductor devices and waste heat recovery. He is the Director of the Thermionic Energy Conversion Center, a multi-university research collaboration aiming to improve direct thermal to electric energy conversion technologies. He is working on the new sustainability curriculum in collaboration with colleagues in engineering and social sciences. He has initiated an international summer school on renewable energy sources in practice.

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