Lessons Learned

Course Redesign for Renewable Energy Engineering Physics Advanced Lab

California Higher Education Sustainability Conference
CSU Campus as a Living Lab
Cesar Chavez Center – Jack Adams Hall - SFSU
Thursday July 23rd 2015
Motivation: to provide **Physics Lab Experiments** and curriculum pertaining to the sustainable and renewable energy infrastructure already present at the CSUEB campus!

The CSUEB Physical Plant (Sustainable Technologies):

- Over 1 MW of peak power solar photovoltaic panels on the rooftops of four buildings (0.2 MW more being added summer 2015!)

Students ran the “Introduction to Fuel Cell Technology Lab”

$600 per fuel cell kit
Students carried out all the steps needed to convert a silicon “wafer” into a working solar cell:

• “Spin coat” a “p-type” wafer of silicon with an “n-type” dopant oxide
• Put the silicon wafer in a furnace – this allows the n-type dopant to diffuse into the silicon
• Dip the silicon wafer in acid to “etch” or “eat away” the silicon oxide
• Make metallic “contacts to the front and back surfaces (silver paint)
• Go out in the sunshine and measure!

Thanks to colleagues at SJSU for use of their Microscale Process Engineering Lab!
Students built an “off Grid” solar station, then designed and built electronic components to compare efficiencies of the commercial system to their own.

This lab was inspired by a Physics Today Article
This open-ended lab allowed students to pursue their own interests; from electrical circuit design to building the panel support structures – the Engineering Physics overlap!
White Papers and a final Oral Presentation on a topic relevant to sustainability:

- The Cost for CSUEB to Subsidize E-car Fuel
- CSUEB Concord Campus Solar Installation Evaluation
- Cost/Benefit Analysis of Parking Lot Solar Canopies at CSUEB
- Carbon Sequester and Sequestration Using Algae Bioreactors
- A review of Fracking and its Effects in California
Field Trips!

Representatives from PG&E and Fuel Cell Energy Inc. provided a "behind the fence" tour of the CSUEB Fuel Cell system.
Pre and Post course assessment surveys:

Assessment focused on content knowledge to be covered in the class on the topic of sustainability and the Physics and technology of solar photovoltaic materials and fuel cell systems:
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Rob Knapp (The Evergreen State College), who presented this at the APS “Physics of Sustainable Energy Conference,” UC Berkeley, April 2014
Assessment

Pre and Post course assessment surveys:

Assessment focused on content knowledge to be covered in the class on the topic of sustainability and the Physics and technology of solar photovoltaic materials and fuel cell systems:

- What is the cost of electric power?
- What is the typical efficiency of a commercial solar panel?
- Define “Sustainability” and can you list an example of sustainability here at CSUEB?

Also asked for feedback on the post course survey, e.g.:

“My favorite experiment was making our own solar cell from the silicon wafer. I learned a lot about efficiencies in solar cells.”
The course redesign of Physics 3281 at CSUEB in 2014 enabled by the Chancellor’s Office Campus as a Living Lab grant:

- **Raised students awareness of sustainability** efforts at the CSUEB campus: **Solar PV** and **Fuel Cell** as part of the physical plant at CSUEB

- Provided a framework to teach Sustainability concepts and Semiconductor Industry Physics and Engineering principles to our students

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COURSE DESCRIPTION:

- Build rugged, portable, off-grid solar electric systems, to power and light schools and orphanages in the world’s poorest countries.
- Learn from a team of CSUEB faculty and highly successful social entrepreneurs who are advancing and using solar technology to create a more sustainable and just world.
- Learn about energy poverty—while doing something about it!
- Learn to teach. Teach to learn. And, if you’ve got what it takes…
- Become a certified We Share Solar Ambassador and
- Share your solar knowledge in Bay Area schools.
Campus as a Living Lab

Final Grant Narrative

Preparation

During the Fall 2013 and Winter 2014 quarters, the PI Helgren and CSUEB undergraduates Marina Longnickel, Matt Diefenbach, Garrett DeCamp and Jordan Dudley worked on preparing the new instructional material to be used in the modified course, Physics 3281, the Advanced Experimental Physics Laboratory course, taught every Spring quarter in the Physics Department at CSUEB. The students, supervised by the PI accomplished the following:

- Researched commercially available Fuel Cell training kits and selected the system offered by the Schatz Energy Research Center at Humboldt State University (two kits were purchased, at a reduced cost due to the intra-CSU purchase, with matching funds provided by CSUEB)
- Tested the Fuel Cell kits and developed handouts and curriculum to be used in conjunction with the kits.
- Developed and tested a procedure to let students in the course “make their own silicon solar cell” from scratch, i.e. starting with a simple silicon wafer, and wrote accompanying handouts and curriculum to be used in conjunction with this new lab.
- Researched and tested various electronic circuits and components to be used with the “building an off-grid solar installation” lab and wrote accompanying handouts and curriculum to be used in conjunction with this new lab.

The PI Helgren also:

- Coordinated with representatives from PG&E and the on-campus Fuel Cell’s manufacturer, Fuel Cell Energy Inc., to provide a guided tour/visit to the CSUAB Fuel Cell facility, both for the re-designed course Physics 3281, and also for a CSUEB Freshman “cluster course” Physics 2004, The Science of Energy.
- Made arrangements for the students in Physics 3281 to visit UC Berkeley and the Advanced Light Source at the Lawrence Berkeley National Lab for tours of labs focusing on and meetings with scientists working on renewable energy related research.
- Arranged for an outreach event at our local community college campus, Contra Costa Community College, to give a presentation on renewable energy technology and to meet with students in the Math, Science and Engineering clubs.
- Advertised the newly redesigned course to the Department of Chemistry and the School of Engineering.
Teaching the Re-designed Lab (Spring Quarter 2014)

The course is taught in a very modular fashion, with students being allowed to select from a wide range of labs which ones they want to work on. In the end I offered sets of experiments/labs that fell under two different categories or tracks; 1) a traditional Physics Track and 2) the new Engineering-Physics Track. Students overwhelmingly selected the newly designed labs which fell under the Engineering-Physics track.

The Curriculum and Experiential Learning included:

- Students working on the new Introduction to a Fuel Cell lab (using an electrolysis step to split water into Hydrogen and Oxygen gas, then using the stored gases to run a proton-exchange membrane fuel cell stack to create electricity, testing the efficiency of each step).

- Students learned how to characterize the efficiency of a solar panel. Prelab exercise of calculate the depth profile for the pn junction using Fick’s law. Students also had an in-class exercise of calculations for average solar panel needs for a California residential home. Lecture on “Figures of Merit” for determining solar panel efficiency: Fill Factor, open-circuit voltage (Voc) and short-circuit current (Isc).

- Every student made their own silicon solar cell from scratch. Students applied a spin on dopant (n-typed, Phosphorous-based) to the silicon (p-type, Boron-doped) wafers and then annealed the wafers (a diffusion doping technique) at CSUEB. The CSUEB EH&S
officer denied my request to etch the wafers, post-anneal at CSUEB so on Friday May 9, 2014 I arranged to visit the San Jose State MPE center to etch the silicon wafers post-anneal. I had contacted Dr. Stacy Gleixner the Director of the Microelectronics Process Engineering (MPE) center to gain access to a clean room capable of etching oxides from semiconductors. She directed me to Neil Peters, the lead lab engineer whom I met that day to help me with the buffered oxide etch (Hydrofluoric acid) step. The wafers came out clean and I returned them to CSUEB for the students to continue working on the following lab period (the following Monday, May 12, 2014). This was the only step the students were not directly involved with, however I covered the fundamentals of this step in a lecture. Students finished processing their silicon solar cell pn-junctions. Metallic front and backside contacts were made a variety of ways: “cold-pressed” Indium technique, silver paint technique and a trio of students opted to run the thermal evaporator to completely coat the backside of their solar cells with an Aluminum film. (I also shared this recipe/curriculum with Prof. Mark Wong at Contra Costa Community College).

- A Tour of the Advanced Light Source at the Lawrence Berkeley National Lab. Doug Taub (CSUEB alumnus from 1974) led a tour for us and Ian Lacey (CSUEB Alumnus from 2012) gave us a tour of the Metrology Lab he works at now. The tour showed off all the beamlines but an emphasis was made on the Materials Science research being performed at the ALS with regards to renewable energy technologies (photovoltaic materials research, battery technology research etc.)
A visit to the CSUEB Fuel Cell (including hard hats, safety goggles and reflective vests!) Students met at the CSUEB Fuel cell located on the North side of campus. Representatives from PG&E (Josh and representatives from Fresno region as well) and from the fuel cell manufacturer Fuel Cell Energy Inc. (Jennifer, Mechanical Engineer) gave an overview of the Fuel Cell set-up located on the CSUEB campus.

Students were each tasked with a Research Project where they were tasked with researching a topic they were interested in related to “Sustainability”, and whenever possible with an emphasis on campus related sustainability efforts/projects. Each student submitted a report and presented their research in a “conference style” format (10 minute talks) during the last week of the quarter. The topics included:

- Cost for CSU East Bay to Subsidize e-car “Fuel”
- Concord Campus Solar Installation Analysis
- Making and Testing an Anti-Reflection Coating for Silicon Solar Cells
- Off-Grid Solar Installation Summary
- A Review of Hydraulic Fracking and its Effects in California
- Carbon Capture and Sequestration Using Algae Bioreactors
- An Environmental and Methodically Objective Analysis of Silicon Manufacturing for Solar Cell Technology

Faculty from Physics, Statistics, Engineering and Chemistry were invited to this Forum.

**California Higher Education Sustainability Conference (CHESC)**

An excellent opportunity arose for the CSU to disseminate its efforts in fostering a greater emphasis on sustainability through its Chancellor’s Office funded Campus as a Living Lab Initiative, namely by reporting on various campuses grant funded efforts in a special panel at the annual California Higher Education Sustainability Conference (CHESC) hosted by San Diego State University in June of 2014. We are all very appreciative of Meaghan Smith, Principal University Planner/Project Manager for the Chancellor’s Office for coordinating the efforts to form this special panel. In the end four faculty members; Erik Helgren and Michael Lee from CSUEB, Margot MacDonald from Cal Poly SLO and Jason Henderson from SFSU (each recipients of CO sponsored Campus as a Living Lab grants), the Assistant Vice Chancellor from the Chancellor’s office, Elvira San Juan, and three students from CSU Fresno were invited to speak at CHESC. The session was well-attended and we all were able to provide guidance and pass along best-practices to interested staff and faculty from community colleges, other CSUs and UC campuses.

**Assessment**

A concept inventory and content knowledge assessment questionnaire was handed out to the students who had taken the course as well as a group of Physics majors who did not take the class (for comparison purposes).

For the content knowledge, there were 8 questions and the Physics 3281 students averaged 6.57/8 correct on the test. In the reference group there were seniors (ready to graduate) and sophomores. The reference group seniors scored a 5.33/8 on the test and the sophomores scored on average a 1.25/8 on the test.

Reference group counted as the “pre-course” test: 3.33/8 = 41%

Post test: 6.57/8 = 82%

Test questions included:
1. What is the cost for electricity?
2. What is a “pn-junction”
3. What do the “p” and the “n” stand for?
4. What is the “fuel” that a fuel cell runs on?
5. What is the definition of efficiency?
6. What is the typical efficiency of a commercial solar panel?
7. How many Watts/m² of sunlight are incident on the surface of the Earth?
8. Can you define “Sustainability” and can you list an example of sustainability here at CSUEB?

Students who took the Physics 3281 course this quarter were asked about their experience in this newly modified course:

- Do you feel the emphasis on renewable energy labs like the fuel cell and the solar photovoltaics was a topic worth learning about?

  Student response was overwhelmingly positive:
  
  “Yes, sustainability is an important topic, although opportunity costs may be high initially”
  
  “Yes I learned a lot about efficiencies in solar PVs”

- What were your favorite experiments this quarter in Advanced Lab and/or what did you enjoy the most this quarter?

  “My favorite experiment was making our own solar cell from the silicon wafer.”
  
  “Off grid Solar Installation; I learned a lot about circuit design and construction.”
  
  “Making a solar cell!”

**Future Efforts**

The Physics Department runs the Physics 3281 Advanced Laboratory every spring quarter and these newly redesigned laboratory experiments will continue to be used in this course. In our efforts to continually improve the curriculum, and to continue our emphasis on sustainability in
the Physics department, I am happy to report that I was able to leverage the funding provided by the Chancellor’s office to redesign this Physics course to obtain internal CSUEB funding to purchase a more advanced Hydrogen Fuel Cell training system, which shall be used in future offerings of this course. The system we are purchasing is the K00-0693 Instructor Training System from Heliocentris Energy Systems Inc., and we have agreed to share the fuel cell apparatus with the Department of Chemistry and the School of Engineering so that more CSUEB students can learn about the Campus as a Living Lab.