A Project-Based Interdisciplinary Program in Sustainable Energy

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Abstract

This paper describes a new program that gives engineering students from the freshman year through graduate school the opportunity to learn interdisciplinary engineering in the sector of sustainable energy through practical projects. Many of today's students enter the University prepared and eager to learn through practical engineering projects, facilitated by modern technological tools and a wide variety of media. This program provides students with the opportunity to work on real life engineering applications, to practice their problem-solving skills, and to make engineering decisions. These skills will be essential when they embark on their engineering careers after graduation.

Keywords

Energy, Education, Sustainability, Interdisciplinary Education, On-line Learning, Solar Education, Renewable Energy, Hybrid Education

1. Introduction

The program has two parts. First, students learn fundamental concepts through an on-line learning [1] approach. The content is available from a website called PVCDROM. Students go to the website, study the material and interactively carry out tasks following a script written by our laboratory. This is an example of a hybrid model [2] of on-line learning since it uses web-based content, but relies also on interactions with instructors and other resources in the Latimer Energy Laboratory. The laboratory is a Santa Clara University facility dedicated to the study of sustainable energy. Students who participate in this on-line study have the opportunity to communicate through chat, email and online threaded discussions with faculty and fellow students. However, students also have the opportunity to attend courses and to have face-to-face interactions with faculty and industry experts. In the second part of the program, students select practical projects, and are paired with a professional in the relevant field, where possible.

The program is called the Latimer Energy Scholars. Students apply for admission, and if selected, participate in the two-part program designed to give them a strong background in sustainable energy. Typically, they study fundamentals during the academic year and work on projects during the summer, or during the academic year. They are supported while doing summer projects through endowment from a $1.3 million grant. The initial class is quite diverse, with representation from the following fields of engineering: biomedical, civil, computer, electrical and mechanical. They are freshmen, sophomores and juniors.

2. Learning the Fundamentals

The fundamentals of sustainable energy are studied through a variety of on-line resources and other media. For example, in the area of silicon photovoltaics (PV), fundamentals are studied on-line with the tutorial PVCDROM [3], which is a comprehensive study of most of the important aspects of silicon photovoltaics. Other examples of study media are: National Instruments and Texas Instruments webcasts, tutorials available from the National Renewable Energy Laboratory (NREL), books in the Latimer Laboratory, solar/sustainability magazines, and materials supplied by industry experts.

Let's look at the use of the PVCDROM in more detail. PVCDROM is essentially an open on-line book with photovoltaic content that can be read, and animated graphics that can be used to actively study properties of interest. Also available are calculators that can be used to find results under characteristics of the reader's choice. The on-line book has eight chapters: Introduction, Properties of Sunlight, PN Junction, Solar Cell Operation, Design of Solar Cells, Manufacturing Si Cells, Modules and Arrays, Characterization. Each chapter has at least 20 sub-sections that we call "pages". For example, in the chapter on Properties of Sunlight there are pages on Blackbody Radiation, Air Mass, and Measurement of Solar Radiation.

Students use this resource to learn the properties of photovoltaics in an active way. They do this by following a series of "sessions" that we have written. Each session, of perhaps four to five pages, covers a few related pages. Students are directed to go to a page, read the material, and then carry out some experiments or calculations. In early sessions students are guided as to what they should do. Gradually they are given more autonomy, and eventually they carry on their own independent learning.

An example of a controllable graphic from PVCDROM is shown in Figure 1. The slider allows the student to vary the blackbody temperature. The example shown in Figure 1 is for T = 5800 degrees Kelvin, the approximate temperature of the surface of the sun. Students vary the temperature to observe the effect of temperature on the peak wavelength and the area of the radiation curve. The results can be checked against calculated values.

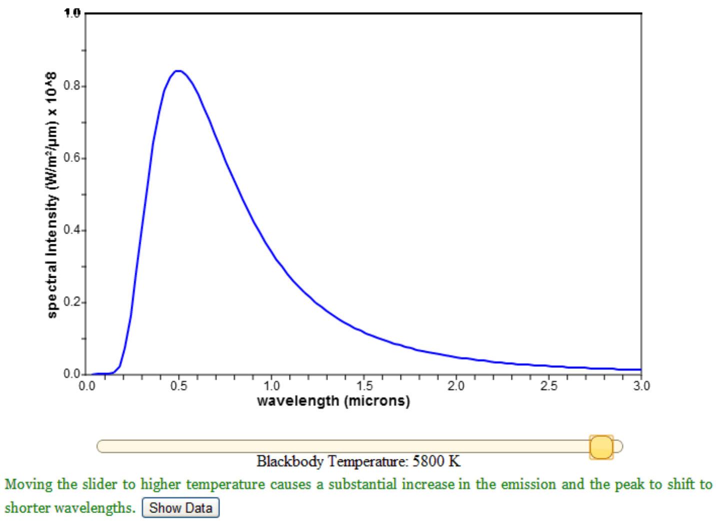

Figure 1: Controllable Graphic from PVCDROM (used with permission).

Several students commented informally that they found the interactive graphics to be very helpful. They also saw the PVCDROM as an excellent resource for future learning.

One feature that makes this a particularly attractive study is its interdisciplinary character. Students study the physics of the sun and of semiconductors, the electrical engineering of cell characteristics and electrical optimization, the mechanical engineering of heat transfer and device and panel design, and the manufacturing engineering of putting it all together to produce a practical device. Figure 2 shows a still shot of a dynamic animation of the manufacturing of a single-crystal ingot of silicon, using the Czochralski process.

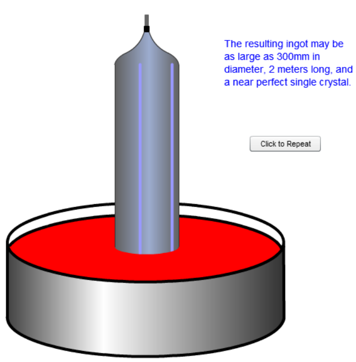

Figure 2: The Czochralski Process graphic from PVCDROM (used with permission).

3. Examples of Projects

In addition to the study of fundamentals, students select a project of interest to them. No effort is made to match their project to their academic department. The interdisciplinary nature of almost all projects is stressed, and in fact most students do not pick a project that necessarily matches their chosen major. Students who complete a successful project and submit an appropriate report earn an additional unit of academic credit. An ideal for the program is that it leads to a senior project, which all undergraduate engineers must complete.

In the summer of 2012 seven Latimer Energy Scholars chose projects in a variety of areas. Each is described briefly here, and then two are presented in more detail.

One student focused on fuel cells, with a plan to study various fuels. Two students spent the summer on the 2013 Solar Decathlon team, working on the selection of appropriate PV panels. One student took on the task of designing a microscope for use in remote regions. The scope uses a smart phone for a readout device, and of course also provides a method for sending the images to anywhere in the world where they can be analyzed. One student chose to spend much of her summer in Uganda working with Solar Sisters on the dissemination of solar devices.

3.1. Solar Sisters in Uganda

Santa Clara University has a long-time commitment to social justice around the world. Our School of Engineering shares that commitment, with a record of many projects designed to improve the lives of peoples in many countries. So, it was not a surprise when one of our Latimer scholars chose to spend the summer of 2012 in Uganda, working the Solar Sister organization [4]. This group has the mission of distributing solar lighting devices in developing countries. At the end of the program the Scholar reported her reaction to the program.

"The experience included the presentation of a technical training component for Solar Sisters' training sessions and learning techniques for effective cost and energy analyses for solar products versus inefficient fuel sources including kerosene. I accomplished my personal research on product development for the developing world through observation and interviews with end users, Barefoot Power, Ultratec, and the Rural Electrification Agency of Uganda. The main deliverables for Solar Sister are promotional and educational videos based on ethnographic in-field interviews. This project is being completed with two other SCU students. As a Latimer Energy Scholar I entered this internship with prior experience demonstrating and explaining solar technologies to those new to the subject. Additionally I was already familiar with solar portable devices in the Latimer Energy Lab including products by d.Light, Angaza Design, and Light Up the World."

This project led to a commitment to bring together over the internet Latimer Energy Scholars and students in Uganda associated with the Nsamizi Training Institute of Social Development. The Institute, founded in 1952, brings development training to Ugandians. Students from Santa Clara and Uganda will work together in the development of projects of value to the Institute. In addition, the Sessions associated with the PVCDROM study will be made available to these students, and in fact to anyone interested.

3.2. Cylindrical Photovoltaic Solar Modules

Two Latimer scholars chose to tackle the study of solar modules which use cylindrical collecting surfaces as opposed to flat collectors. This technology is very common in solar thermal systems in which water or some other medium is heated by the sun, and then used directly as warm or hot water, or converted by some thermodynamic process into another form of energy. Much less common is the use of this configuration for the generation of photovoltaic energy. A major example of the latter is the system developed by the now-defunct Solyndra [5]. This company declared bankruptcy in September of 2011. Subsequently, the Latimer Energy Laboratory obtained a Solyndra panel, making some initial current and voltage tests. The panel is shown in Figure 3.

Figure 3: Solyndra PV module, students and mentors.

In the summer of 2012 two Latimer Scholars took on the project of characterizing the performance of the panel, theoretically and through measurements. There are three reasons for taking on this task. First, studies and analyses done by Solyndra are generally not available, as they are their intellectual property. It was our belief that the technology should be carefully studied, to see if there was a

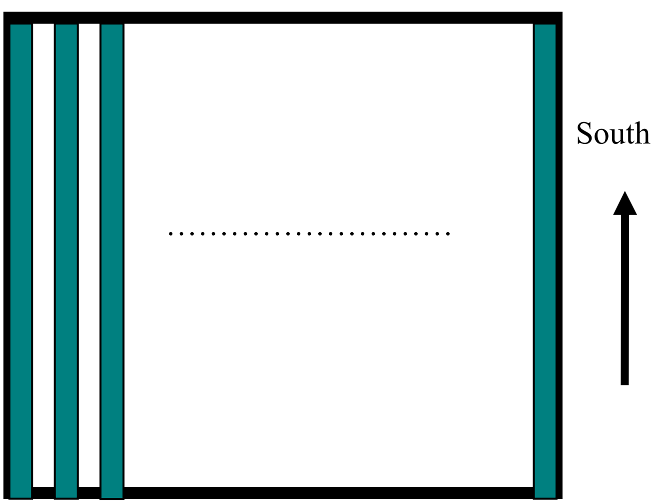

Figure 4: Layout of Solyndra Module (top view).

logic for someday returning to this form of PV module. Second, much of the study has relevance to solar thermal, which is a thriving global industry. Third, it makes a wonderful teaching tool, stretching across many technical fields, including mechanical engineering, chemistry, glass making, optics, reflectivity (albedo), and electrical engineering, measurements.

The basic structure of the Solyndra panel is shown in Figure 4. Four of the total of 40 cylindrical tubes are shown. Each is 22 mm inch in diameter one meter long, and the spacing of tubes is 44 mm. Assume that the module is horizontal. This is the normal case since it is designed to lie flat on a horizontal roof, which allows for a very simple installation process. Assume that the module tubes are oriented north and south, as suggested by the arrow. Then on the equinoxes the sun will rise due east, or to the left on the figure, and set due west, on the right. At solar noon the sun would have an elevation angle of 90 – L degrees, where L is the latitude of the site.

Consider the special case where the tilt angle of the panel is set at L. Then the sun will always be perpendicular to the tubes. This case allows for a simplification that facilitates initial study of the response of the panel. If the sun is always perpendicular to the tubes, the radiation on the tubes would seem at first to be constant throughout the day.

This is because the sun always sees the same apparent tube area. And this is indeed the case, up to a point. And this gives the panel its solar tracking property. It is as if the panel always points at the sun, producing a flat power production yield throughout the day. Two factors keep this ideal case from being realized. The first is that early and late in a day there will come a time when the tubes begin to

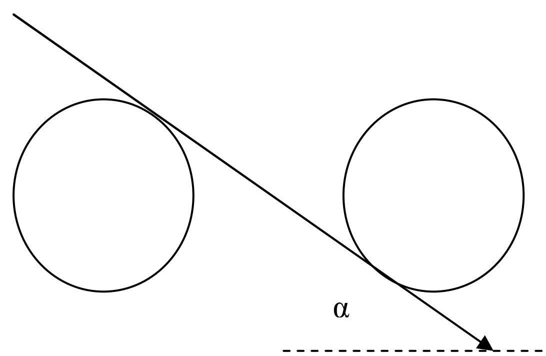

Figure 5: Cross-Section of Cylinders showing critical angle.

shade each other. This effect is shown in Figure 5, which shows the ends of two tubes with diameter d, and spacing s. A ray of sunlight with elevation angle α above the horizon is shown as the slanted arrow. If s = 2d, it is easy to show that if α is less that 30 degrees the tube on the left will shadow or hide a part of the tube on the right leading to less power production. The net result is that the response will be flat for α greater than 30 degrees. For α less than 30 degrees the response falls off as if the module were a flat panel.

There is a second factor that keeps the ideal case from being realized. If α in Figure 5 is greater than 30 degrees, and the ray shown does not hit the tube on the right it will reflect off the surface under the module, and bounce back up to hit the bottom of another tube. This phenomenon is optimized by giving the surface under the module as high as possible a solar reflectivity (called the "albedo"). Hence we paint the roof of the structure that the panel sits on white, with an albedo as close to one as possible. Values near 0.85 to 0.90

We have made a number of assumptions to get to this point, namely that the module points south, that it is tilted at latitude, and that is the day of the equinox. None of these are generally true, and the analysis must take account of this fact. The Latimer scholars adapted analyses from papers written for solar thermal studies [6-10], and they also made day-long measurements of solar power production of the lab's Solyndra module. An example of the latter is shown in Figure 6.

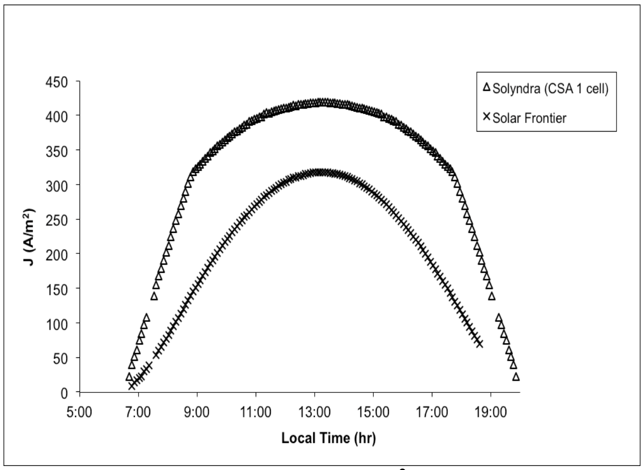

Figure 6: Short circuit current per m^2 for Solyndra (top curve) and Standard CIGS PV module from Solar Frontier.

The experimental results confirm and support the arguments given above. The cap of the response for α greater than 30 degrees is due to reflection from the material under the module. Experiments showed that if a black surface is placed under the module the response for α greater than 30 degrees was essentially flat. To quantify the effect of surface albedo the students measured the albedo of a Teflon strip, used as a standard against which the real surface can be compared. This was a collaboration between the Latimer Energy Laboratory and Santa Clara's physics department.

The students believed that a serious examination of the technology should be done. To accomplish this they made a number of day-long measurements of the short circuit current of a Solyndra panel. They then compared these experimental results to a closed form theoretical analysis of evacuated-tube thermal panels, and they carried out an analysis of their own. Finally, they compared the current and power with that of standard flat panels. Among their outcomes was the identification of a cosine/linear response that is unique to this technology, not found in flat plate panels. In this case, the students were mentored by a professional engineer, who is one of the co-authors of this paper.

4. Assessment of Student Learning

Student learning was assessed in two ways. After each PVCDROM-based section, the students were asked to report on their learning experience, engagement and knowledge acquired. Below is an example of a response obtained by a student after a session on radiation:

"Many commonly encountered light sources, including the sun and incandescent light bulbs, are closely modeled as "blackbody" emitters. A blackbody absorbs all radiation incident on its surface and emits radiation based on its temperature."

The instructor expands on the student's comments and knowledge by asking the student additional questions, presenting additional examples, showing real-life measurements and mentioning related areas that where not mentioned in the PVCDROM. For example, expanding on the sources that are not well modeled by blackbody radiation, such as, compact fluorescents and light emitting diodes and obtaining real-life measurement of their spectrum. Also, mentioning that albedo of a black body is zero and obtaining albedo measurements of different surfaces.

We also sought to assess what students learned from projects. One of the students who worked on the cylindrical solar module project reported that he learned about the process of R&D and how it was done. He reported that:

"R&D takes a lot longer than I thought it would. We had to repeat a lot of steps. We learned the differences between basic and applied, or product development, R&D. I would definitely like to go into R&D after college."

This was the sentiment of the other student working on the project, who said that R&D was now a "career possibility." He reported:

"I like looking at new things that others haven't looked at before. We learned a great deal about photovoltaics and electrical engineering. For example, we learned that little things, like good electrical connections, matter. We learned about things like current and power density and how to connect and use measurement and data-logging instruments. Since I am a hands-on learner, the project helped me to understand the CDROM and on-line materials. I also learned that there were a lot of papers out there that could have been looked at before Solyndra was given the money (from the U.S. DoE)."

Assessment was also facilitated by the use of Camino, a Learning Management System (LMS) that has been used at Santa Clara University since 2003 [11]. The Camino Suite of teaching and learning tools enables efficient and effective development, delivery and management of courses, course content and learning outcomes. Faculty can use online drop boxes to receive and grade uploaded assignments; post documents or project data online, establish and monitor discussion boards and chat; create group space for discussions or for collaboration on projects; administer surveys or quizzes; and send and receive course email.

5. Conclusion

It is our belief that this combination of on-line learning, supplemented by laboratory work, with applications to real-life projects offers an excellent approach to interdisciplinary engineering education and warrants further testing. Future work will expand the use of the Camino platform so that participating students can share completed session reports from the PVCDROM as well as information, insights and data from their projects.

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SESSION 4A

Tuesday March 5, 2013
1:30PM-3:30PM
Electronics Education
Chair: **Vivek Joshi**, Global Foundries

1:30PM
4A.1
Engaging Undergraduate Students in Nano-Scale Circuit Research using Summer Internship
Hamid Mahmoodi[1], *Jesus Garcia*[2], *Joshua Lohse*[2], *John Paulino*[2], *Hector Prado*[2], *Atul Balani*[1], *Sridevi Lakshmipuram*[1], *Cheng Chen*[1], *Amelito Enriquez*[2], *Hao Jiang*[1], *Wenshen Pong*[1], *Hamid Shanasser*[1]
[1]San Francisco State University, [2]Cañada College

1:50PM
4A.2
Instrumentation Laboratory at a Foreign Study Center with Concurrent Instruction
Erik Bardy and Mark Reuber
Grove City College

2:10PM
4A.3
A Project-Based Interdisciplinary Program in Sustainable Energy
Tim Healy[1], *Greg Smestad*[2], *Jasmin Gonzalez*[1]
[1]Santa Clara University, [2]Sol Ideas Technology Development

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Abstract

The purpose of the abstract presented is to summarize the Latimer Energy Scholars Program at Santa Clara University. This program offers students with various engineering and science backgrounds an opportunity to tackle interdisciplinary engineering projects in the sustainability field. During the projects the students are faced with open-ended real life engineering decisions, and they utilize their educational background and problem solving skills to achieve their tasks. Available resources to accomplish these tasks include cutting-edge tools in the lab as well as support and coaching from fellow students, professors and experts in the field.

The Latimer Energy Scholars program utilizes a hybrid educational model. Through this approach we provide students with a wide variety of resources (on-line and off-line) and enough educational freedom to decide their own path of interest. Students learn the fundamentals of sustainable energy through their current engineering curriculum, on-line tutorials and webcasts, selected books and magazines in the area, and face to face interaction with professors and industry experts in the field.

This developing program has already shown signs of success. Currently, there are ten students involved in the program, with a number of challenging projects in the solar/sustainability area. We expect to continue to enhance the program to support many more students in their interdisciplinary engineering growth.

2:30PM

4A.4

A Laboratory on the Configuration of Electric Power Substation Monitoring and Control Based on the SEL751A Relay and an Induction Motor Drive for a Three Phase Power Supply

Ishwar Singh[1] *and Tom Wanyama*[2]

[1]Mohawk College, [2]McMaster University

2:50PM

4A.5

"What does your Building Compute, Mr. Foster?" How Computer Science Students can Learn from Architecture and the Built Environment

David Claveau

ASU

3:10PM

4A.6

An Interdisciplinary Project in Sustainable Development Based on Modern Visual Programming Environments and Web 2.0 Technologies

Daniela Giordano and Francesco Maiorana

University of Catania

Source Information:

http://www.iedec.org/English/Archives/2013/Technical_Sessions/108.html

http://www.iedec.org/English/Archives/2013/Technical_Sessions/Technical_Sessions.html#A4

http://www.iedec.org/English/Archives/2013/Program_At_a_Glance.html