Experience with Enhancement of Green Energy Manufacturing Learning in Course and Laboratory Development

Dr. Richard Chiou, Drexel University

Dr. Richard Chiou is Associate Professor within the Engineering Technology Department at Drexel University, Philadelphia, USA. He received his Ph.D. degree in the G.W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology. His educational background is in manufacturing with an emphasis on mechatronics. In addition to his many years of industrial experience, he has taught many different engineering and technology courses at undergraduate and graduate levels. His tremendous research experience in manufacturing includes environmentally conscious manufacturing, Internet based robotics, and Web based quality. In the past years, he has been involved in sustainable manufacturing for maximizing energy and material recovery while minimizing environmental impact.

Prof. Tzu-Liang Bill Tseng, University of Texas, El Paso

Dr. Tseng is a Professor and Chair of Industrial, Manufacturing and Systems Engineering at UTEP. His research focuses on the computational intelligence, data mining, bio- informatics and advanced manufacturing. Dr. Tseng published in many refereed journals such as IEEE Transactions, IIE Transaction, Journal of Manufacturing Systems and others. He has been serving as a principle investigator of many research projects, funded by NSF, NASA, DoEd, KSEF and LMC. He is currently serving as an editor of Journal of Computer Standards & Interfaces.

Dr. Radian G Belu, University of Alaska Anchorage

Dr. Radian Belu is Associate Professor within Electrical Engineering Department, University of Alaska Anchorage, USA. He is holding one PHD in power engineering and other one in physics. Before joining to University of Alaska Anchorage Dr. Belu hold faculty, research and industry positions at universities and research institutes in Romania, Canada and United States. He also worked for several years in industry as project manager, senior engineer and consultant. He has taught and developed undergraduate and graduate courses in power electronics, power systems, renewable energy, smart grids, control, electric machines, instrumentation, radar and remote sensing, numerical methods, space and atmosphere physics, and applied physics. His research interests included power system stability, control and protection, renewable energy system analysis, assessment and design, smart microgrids, power electronics and electric machines for non-conventional energy conversion, remote sensing, wave and turbulence, numerical modeling, electromagnetic compatibility and engineering education. During his career Dr. Belu published ten book chapters, several papers in referred journals and in conference proceedings in his areas of the research interests. He has also been PI or Co-PI for various research projects United States and abroad in power systems analysis and protection, load and energy demand forecasting, renewable energy, microgrids, wave and turbulence, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

Dr. Michael G Mauk P.E., Drexel University
Mr. M. Eric Carr, Drexel University

Mr. Eric Carr is a full-time Laboratory Manager and part-time adjunct instructor with Drexel University's Department of Engineering Technology. Eric assists faculty members with the development and implementation of various Engineering Technology courses. A graduate of Old Dominion University's Computer Engineering Technology program and Drexel's College of Engineering, Eric enjoys finding innovative ways to use microcontrollers and other technologies to enhance Drexel's Engineering Technology course offerings. Eric is currently pursuing a Ph.D in Computer Engineering at Drexel, and is an author of several technical papers in the field of Engineering Technology Education.

Regina Ruane Ph.D., Drexel University (Eng. & Eng. Tech.)

Experience with Enhancement of Green Energy Manufacturing Learning in Course and Laboratory Development

Abstract

The purpose of this paper is to share the experience and early results from an interdisciplinary project that integrates theory and practice in green energy manufacturing with course and laboratory development. This project links new courses in renewable energy, clean energy, and energy efficiency with specialized laboratories that fuse green energy into manufacturing engineering education. Two main components are used to incorporate sustainability into the green energy manufacturing project, including: (1) renewable energy and (2) manufacturing energy efficiency. This paper presents how long-term sustainability and support are established through a variety of mechanisms including the energy mission, the awards of federal grants, design projects, partnership, and online learning community. This paper also shows the development process, design and content of an interdisciplinary sustainability curriculum that integrates manufacturing with the green energy while enlivening campus-community relationships through student projects. Capitalizing on the success of the implementation of green energy manufacturing in the curriculum through the support of federal grants since 2012, the quality of curriculum, course offerings, and laboratory facilities are improved to meet the project mission. The project outcomes help prepare students to: apply discipline-specific theory, conduct experiments, and use real-world experience to interpret, analyze, and solve current and emerging technical problems in green energy manufacturing.

1. Introduction

There is a need to instill sustainability awareness and concepts among undergraduate students, in order to ensure that sustainable production will be achieved in the near future. Sustainability has four basic aspects: the environment, technology, economy, and societal organization. Conventionally, engineers are taught to deal with technology development and economic analysis assessing the viability of a process, a product, or a project, being less familiar with the optimization of environmental factors. However, schools with undergraduate engineering or engineering technology programs are working to include environmental sustainability and sustainable design into their curricula. Teaching sustainability and green design in engineering or technology curricula has increasingly become an essential feature of our engineering education system. Sustainable engineering is about design that recognizes the constraints that are applied by natural resources and the environmental system. It applies to all of engineering systems that interact with the environment in complex and important ways. However, the need for engineering students and practicing engineers to understand sustainability concepts has been noted by many educators.

Today, we need a comprehensive industrial strategy to rebuild manufacturing across the United States. A critical component of a new industrial policy will be a program to make the U.S. the world's leading manufacturer of new, green technologies and components. It makes good economic sense and we have the capacity to do it. Renewable energy technologies provide three to six times as many jobs as equivalent investments in fossil fuels, when manufacturing, installation, operation and maintenance jobs are taken into account. The central findings show that a national Renewable Electricity Standard (RES), and other policies that can increase the U.S. electric generation share to 25 percent renewable content by 2025, would stimulate enough demand for the component parts needed to make wind turbines, solar panels and other clean energy technologies to create 850,000 jobs in existing U.S. manufacturing firms across the country. Motivated by energy security requirements and the desire to create a sustainable and safe environment, there is a growing need to transition gradually from fossil fuels to emerging and renewable energy sources. The Energy Information Administration predicts that U.S. energy consumption will increase at a rate of 1.1% annually, but that U.S. energy production will only increase at a rate of 0.9% annually, from now until 2030[1-4]. These projections are based in part on current usage of renewable energy sources. To narrow the gap between consumption and production, additional usage of energy sources other than fossil fuels is required.

DREXEL University (DU) works in collaboration with The University of Texas at El Paso (UTEP) on a collaborative project on Green Energy Manufacturing Education. In this project, we formulate two geographically separated virtual teams between UTEP and DREXEL, collaborating on green energy manufacturing education and research over the Internet. Implementing a mixed method of research design, students and faculty involved in the project are assessed in formative and summative formats to measure the efficacy of the project. Our project aims to develop and establish an integrated research-oriented teaching facility to support and enhance learning in the area of green energy manufacturing by developing a packaged suite of comprehensive laboratory experiments and modules. In this study we incorporate green energy and sustainable manufacturing into our undergraduate courses and laboratory experiments for student learning purposes. Our approaches are: (1) redesigning existing courses through development of new laboratory module materials that meet the project objectives and (2) developing new laboratory courses that address specific topics related to sustainability, such as clean energy, green manufacturing, and life-cycle assessment.

2. Green Energy Manufacturing Education and Practice

Green design and manufacturing for sustainability are emerging fields in recent years and a sustainable development model for modern industries. They encompass the concept of combining technical issues of design and manufacturing, energy conservation and efficiency, pollution prevention, health and safety of communities and consumers. Many industries are directing their efforts to reduce the environmental impacts of their products and services. On the other hand, to remain competitive in the global economy, the industries need to train engineering and professionals to understand the impact of their decisions on the environment and society. It is important for universities to prepare these future engineering technologists to meet this need.

The Accreditation Board for Engineering and Technology (ABET)[5-6] requires that graduates be able “to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability ”. The topic of sustainability has become part of corporate strategy, consumer choice processes, university initiatives, engineering, and technology programs within the business discipline[7-11]. We are moving toward more sustainable business practices and education, as a direct result of an increasing awareness of the significant green manufacturing, covering a broad spectrum, from development of green technology products, implementation of advanced manufacturing and production technologies, and introduction of energy efficient and environmentally friendly manufacturing processes and systems, from the plant floor to the enterprise level, and the whole supply chain. We are interpreting green energy manufacturing as follows:

1. Manufacturing of green technology products, in particular, those used in renewable energy systems and clean technology equipment.
2. Manufacturing process and system control to address energy and environmental concerns, such as reducing pollution and waste, reducing emissions, minimizing natural resource and energy usage, recycling and reusing what was considered as waste before, etc.
3. Changing the education to include sustainability, green manufacturing, and efficient design into the engineering and engineering technology curricula.

3. Course Development

Course Description and Instruction Design

We have developed two new courses on renewable energy technology and industrial energy management. The first course EET 320 Renewable Energy Technologies was focused on clean technology, green engineering and sustainable design in terms of green manufacturing and was first offered as special topics during the Summer quarter of 2013. It provides an introduction to the renewable/alternative energy systems with an emphasis on those utilizing solar and wind technologies, storage energy systems, and the other renewable energy systems, such as wave energy, geothermal, etc. The students learn how these technologies work to provide electrical power and get a glimpse of the capabilities foreseen for the future needs. Renewable energy technology course provides an introduction to energy systems and renewable energy resources, with a scientific examination of the energy field and an emphasis on alternate energy sources and their principles and applications. The class explores society's present needs and future energy demands, examine conventional energy sources and systems, including fossil fuels and nuclear energy, and then focus on alternate, renewable energy sources such as solar, wind power, geothermal, and fuel cells. Energy conservation methods are also emphasized[12-16] in the course. Students are expected to be well-rounded in general renewable energy issues and conversion technologies.

INDE 420 – Industrial Energy Systems

The course INDE420 Industrial Energy Management, offered during the fall quarter of 2014-2015. The energy management field is experiencing significant growth, due to the restructuring of the utility industry, the building automation, and increasing demand for energy services. There is a growing need for engineers with skills in energy, environmental, and facilities management. This paper presents the development of the undergraduate course in the area of energy management and industrial energy systems. The course objectives are to study energy management methods and procedures as performed in modern residential, commercial and industrial facilities. "Energy management" is a broad term for managing available resources to make the most efficient use of energy. Courses with "energy management" in their names or descriptions often cover environmental and economic issues as well as the implementation of practical solutions.

The class is planned for 10 weekly lectures of 3 hours each, which represents 11 weeks (with a final exam) of a regular quarter. Lectures are intended to be delivered by either the instructor or a specialist in the topic being taught. Two laboratory sessions on the major renewable energy systems are embedded in this course. The last section of each lecture (each divided in three major sections: resources, system components and characteristics, and design) focuses on the design of the different products and/or systems that produce energy from renewable resources. This allows the students to understand how these products are made so they can understand further on how they are manufactured. The class is evaluated through two exams in order to assess the level of the student understanding of the course materials. The course is broken down into ten modules, including

1. Introduction to Industrial Energy Systems Energy, Energy Management, Techno-economic Optimization of Resources in Industrial Equipment and Energy Systems,

2. Fundamentals: Units: Finance, Electrical, Thermal; Standards and Policy, Energy Bills, Energy Audits, Savings Analysis, Managing Energy Resources with the Corporate and Plant Information Technology System,

3. Energy Conversion Equipment Characteristics; Understanding Energy Bills, Economic Analysis and Life Cost Cycle,

4. Lightning; Mid-term Exam Review,

5. Mid-term Exam; Energy; Heating, Ventilating, and Air Conditioning,

6. Boilers and Steam Distribution Systems; Industrial Energy System Optimization Methods and Strategies; Optimization of Size and Design Parameters; Influence on the Environment,

7. Control Systems and Computers; Controls, Measurement, Verification, Modeling,

8. Energy Systems Maintenance; Insulation; Economics of Energy Conversion in Industrial Energy Systems,

9. Motors, Compressed Air Systems, Energy Management Systems (EMS), Data Analysis, and

10. Smart Grid, Alternative Energy Sources, Green Buildings.

4. Green Energy Manufacturing Laboratory

DREXEL and UTEP have been working on the development of a green energy manufacturing laboratory for student learning experience in the emerging fields of renewable energy and green manufacturing. The development involves a creation of a series of experiments to stimulate discoveries that promise to sustain a wave of new technological innovations on energy and manufacturing throughout the world. The needs for engineering students and professional engineers to understand sustainability concepts and concerns have been noted by educators, scientists or engineers and all engineering students need to become versed in sustainability ideas. This paper describes key factors in enhancing the ability of future engineering graduates to better contribute to a more sustainable future, preserving natural resources and advancing technological development. Two main components are used to incorporate sustainability into the green energy manufacturing laboratory, including: (1) renewable energy and (2) manufacturing energy efficiency. The efforts presented in the project also include life-cycle assessment, development of innovative thinking skills, better understanding of sustainability issues, and increasing students' interests in the engineering and technology programs.

Renewable Energy Experiments

Since the project started in Fall of 2012, DU and UTEP have been continuously involved with the implementation of renewable energy experiments in different courses that are related to green energy manufacturing, including EET320 Renewable Energy Technology, MET205 Robotics and Mechatronics, and MET101 Manufacturing Materials. For example, EET320 (Renewable Energy Technology) consists of eight in-class lectures and two laboratory sessions. In the ten weeks of the term, students were given a broad idea of renewable energy manufacturing and then upcoming technologies in green energy manufacturing. The laboratory sessions were divided in two sessions covering three wind energy experiments and two solar experiments. Students performed experiments on Lab-Volt kits.

The Lab-Volt wind turbine equipment consists of a dynamometer and a wind turbine generator that is coupled through a pulley. The turbine speeds can be altered by simulating the effect of different wind speeds. The solar energy equipment consists of a monocrystalline solar cell and a bright light source, intended to replicate solar energy. The De Lorenzo GREEN KIT comprises smaller solar panels and wind turbines. It also has a small DC fan and motor. Generated energy can be directly coupled with these equipment and students can observe renewable energy being put to use. This system communicates through a USB cable with the LVDAC-EMS software that runs on the computer. This software can be used to obtain real-time data from the system and save/export data for further analysis.

During the first week, the Voltage vs Speed Characteristics of a Wind Turbine is the first lab to be performed. The objective of this experiment is to understand the effect of generator speed on the amplitude and frequency of the generated voltage. Experiment 2 gived students an understanding of the torque/current characteristics of the wind turbine generator. Once the effect of velocity and torque is studied, the students take the next step in Experiment 3 by studying the relationship between the output power and wind speeds.

During week two, the students perform experiments related to solar energy using solar cells. Figure 1 shows students performing experiments on the solar kit. This kit consists of a bright source of light that simulated solar energy. The mono-crystalline solar panel is excited with this light source. In the first experiment, students study the fundamental concept of a solar cell. The experiment introduces students to the E-I curve of a PV cell. In the succeeding experiment, students study the effect of temperature on solar cells.

Figure 1: A short demonstration of the De Lorenzo GREEN KIT

The DeLorenzo Clean Energy and Energy Efficiency kits are demonstrated to the students in MET101 Manufacturing Materials. Different experiments such as the effect of tilt and shade on solar panels are performed. A representative demonstration of these effects is shown by coupling the power output to a DC-motor. This direct supply of power to instruments helps students understand this concept to greater depth. The laboratory sessions were followed by a feedback evaluation. A questionnaire was circulated amongst the students who answered them while maintaining anonymity. The general feedback received was overwhelmingly positive. Students could follow the manuals very well and understand the goal of the experiment.

Example Lab: Wind turbine experiment

Modern wind generators, and the wind farms that host them, can provide large cities and even entire rural states with sufficient power to operate homes and businesses, alike. Modern wind turbines are very powerful in generating electricity; however, their power output is defined by more than just wind speed. This experiment will demonstrate some fundamental principles behind wind turbine design and performance criteria using established formulaic equations that define the limits of wind power generation. The wind equation is used below.

$$\text{Power} = 0.5\ C\rho AV^3$$

Where ρ = Air Density, C= Efficiency of Performance, A = Front Area, and V = Velocity of wind.

Position the wind turbine directly in front of the fan at a certain distance. You might also want to secure the wind turbine with tape to the base, as the wind from the fan may tend to move it. Set the multidecade resistor to 10 ohms. Set the Power 2 and Load 1 to ON to connect the 10 ohms load to the wind turbine. Start the ECO STEM software and click on the delete icon to clear any previous data. Switch ON the fan to the highest speed sitting. Allow the wind turbine to come up to speed then click the Screen Capture icon to record the voltage, current and power at this speed setting. Adjust the fan speed setting to the middle or medium speed position. Allow the wind turbine to adjust to this speed setting and click the Screen Capture icon to record the voltage, current and power at this speed setting. Adjust the fan speed to the lowest speed setting. Allow the wind turbine to adjust to this speed setting and click the Screen Capture icon to record the voltage, current and power at this speed setting.

Example Lab 1: Blade Number and Pitch

The objectives are to become familiar with the DL Green Kit and wind turbine module and Better understanding of the effect of number of blades and pitch angle on output power. Along with blade pitch, or angle, using the right number of blades for a given wind condition is important in extracting the maximum electrical power from a wind turbine. In this experiment students gain an understanding of the choices between the numbers of blades and blade pitch that are necessary to produce the most power.

Position the wind turbine directly in front of the fan at a certain distance. You might also want to secure the wind turbine with tape to the base, as the wind from the fan may tend to move it. Set the multidecade resistor to 10 ohms. Set the Power 2 and Load 1 to ON to connect the 10 ohms load to the wind turbine. Start the ECO STEM software and click on the delete icon to clear any previous data. Switch ON the fan to the highest speed sitting. Based on the below Table, setup the wind turbine with the number of blades at the blade angle and record the electrical power by the following steps. Switch ON the fan to the highest speed sitting. Allow the wind turbine to come up to speed then click the Screen Capture icon to record the power at this speed setting.

Example Lab 2: Wind Turbine Maximum Power Point

The objectives of the experiment are to 1. Become familiar with the DL Green Kit and wind turbine module. 2. To understand Maximum Power Point (MPP) and its definition, and 3. To understand the effect of Load resistance on a solar panel. Modern wind generators, and the wind farms that host them, can provide large cities like San Francisco and even entire rural states with sufficient power to operate homes and businesses, alike. This experiment demonstrates how to find a Maximum Power Point (MPP) where the wind turbine generates the most electrical power at a given wind speed. The goal of this experiment is to find the MPP at the fastest fan speed setting using multiple resistor loads.

5. Online Learning Community to Engage DU and UTEP Students in Green Energy Manufacturing

Technology-supported collaborative learning in higher education supports the development of new tools to support collaboration, the emergence of constructivist-based approaches to teaching and learning, and the need to create more powerful and engaging learning environments. The development of an online setting for engineering undergraduate students would foster student engagement and keep records of student cooperative/collaborative work, allowing students the chance to review past posts. Research has linked collaborative tasks to student engagement in knowledge construction. Moreover, instructors can monitor student understanding and achievement in collaborative learning activities. In addition, students can review what they wrote or what their peers wrote, and instructors can analyze the discourse of team members using semiautomatic data analysis procedures for facilitation, moderation, grading purposes, and research[17-20].

Studies examining cooperative, competitive, and individualistic learning using computers have found that computer-assisted cooperative learning yields higher quantity and quality of daily achievement, greater mastery of factual information, and greater success in problem solving than computer-supported individualistic learning. The development of an online community to engage and support undergraduate students enrolled at DREXEL and UTEP would allow for engagement and collaborative learning and engagement in Green Energy Manufacturing. The community would offer students the opportunity to interact with other students in their major around the topic of Green Energy Manufacturing through online threaded discussions. Such interaction provides:

- participant engagement through meaningful discussions regarding academic experiences
- support and resources to the student community
- opportunities to share learning and wisdom
- the emergence of a user community centered on the advancement and support of undergraduate engineering students at DREXEL and UTEP

The development of a secure Facebook group to engage and support undergraduate students enrolled at DREXEL and UTEP would allow for engagement and collaborative learning and engagement in Green Energy Manufacturing. The Facebook group would offer students the opportunity to interact with other students in their major around the topic of Green Energy Manufacturing through Facebook posts. The group page would allow students opportunities to collaborate and interact with other students in the same discipline and discuss their learning and questions they have. Such interaction provides:

The participants of this study were drawn from an online Bachelor of Science Education Program at a medium-sized private university, located in a northeastern city in the United States and from a large, public university in a southern city in the United States. Students enrolled in the University of Texas at El Paso's IE4395/IE5390/MFG5390, Green Energy Manufacturing, and DREXEL University's INDE 420, Industrial Energy Systems, were provided the opportunity to join the private and secure Facebook Group, DREXEL-UTEP Green Energy. The Facebook group page features a secure login for students, faculty, and staff. Additionally, this group page offers privacy for the users in that the posts on this page are only visible by those who have joined the group.

The DREXEL-UTEP Green Energy Facebook Group features discussion prompts for the students. The discussions began on September 29, 2014. The students posted their comments and discussed concepts related to each topic with knowledge and experience they have gained through their field and courses. Students were able to post files (MATLAB and LabVIEW) and discuss the content of these files with other DREXEL and UTEP students. When the discussions were complete on December 19, 2014, Author 1 downloaded and printed all of the discussion forums. All personal identifiers were removed from the discussions data. The data was then prepared for social network analysis.

The Facebook account allows for a neutral host to create an established group for students to participate in discussion. The group was made private to prevent any public eyes from viewing course related material and to respect the privacy of students from both universities. Topics are routinely posted to allow students to engage in productive discussion with regards to green energy manufacturing. The social interaction with students allows the exchange of information to become direct and allow real time responses to become instantaneous opposed to other methods of information exchange. The students are first encouraged to give a brief description of their personal experience and field of study. The students then share either course related material with one another or display general knowledge to other students. The idea and knowledge exchange is beneficial to understanding of material and to enable students working on time constrained projects.

6. Student Assessment

There were 20 students enrolled in the course in INDE420 Industrial Energy Systems. The enrolled students are from engineering and technology programs. Students' feedback and evaluation of the course have been good. Table 1 shows the summary of student evaluation of the course for the Fall quarter 2014.

Table 1: Student evaluation

	Questionnaire
Q1	Are the course topics challenging and interesting?
Q2	Have you learn more than expected with the course?
Q3	A team project will be useful to you?
Q4	It will useful to add a laboratory component to future INDE 420 (4 credits version of this course)?
Q5	Please provide an overall evaluation of the course.

Table 1 Questionnaire for the evaluation of the industrial energy systems course At the end of the quarter, all students have been requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 1. According to the results, the new industrial energy system course received a 4.2 (and 0.95 standard deviation), on 5.0 point ratings, for all academic years when the course was offered, compared with an average rating of 3.4 for the all courses and years at our technology program. The results from the students' feedback have been positive. The majority of students felt also that such projects enhanced their understanding of the theoretical materials and made the course more interesting.

7. Conclusions

For the past years, our focus has shifted towards incorporating green energy manufacturing topics in our course and laboratory development. We assign to our students the experimental topics related to renewable energy, power systems, or green energy manufacturing. These experiments provide multi-disciplinary collaboration and valuable hands-on experience to the students. In addition to useful lessons on teamwork and project management, the projects provide working demonstration of green energy manufacturing systems. To enhance the hands-on experience, the laboratory experiments have been restructured as a laboratory course on clean energy and energy efficiency. The goals of all the experiments are to explore and enhance student understanding of the fundamental concept of design-for-environment (dfE) and hands-on learning of green energy manufacturing.

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