# Educating Engineers in Sustainability through Undergraduate Engineering Clinics

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## Abstract

Over the past decade dozens of undergraduate engineering students at Rowan University have been trained in many aspects of sustainability through undergraduate engineering clinics. These include freshman, sophomore and junior/senior clinic experiences built upon the medical school model. The University's College of Engineering is at the forefront of including engineering clinic in the full breadth of the undergraduate engineering experience and has been reported on in many publications [1-3]. Our work enhancing sustainability education using this clinic model is summarized as well in many publications [4-16] and curricular experiences in clinic over this period where critical skills for sustainability (such as life cycle assessment, renewable energy feasibility studies, energy efficiency assessments in buildings, wind assessments, and photovoltaic system designs) are imparted through the use of project based learning. It is found through assessment that life-long learning is encouraged by the clinic experience and dozens of young engineers have entered the renewable energy industry as a result of high levels of interest being developed and these skills being imparted in their undergraduate education. The elements of sustainable design are described as well as how those fundamentals are transmitted through the clinic curriculum at each level of the engineering undergraduate education.

**Keywords:** clinical experience, project based learning, engineering clinics, sustainability education, renewable energy systems.

## 1. Introduction

The engineering clinic sequence at Rowan University has been found to be an extremely useful pedagogical tool to accelerate student learning in sustainability and an effective introduction to many aspects of sustainability education including: energy analysis, renewable energy assessment, renewable power system design. Many engineering curricula around the world are becoming increasingly challenged to incorporate new knowledge, rapidly advancing technology and cutting edge discoveries into the pedagogy while assuring adequate coverage of the fundamentals of engineering and learning critical to success. This pressing challenge encouraged the designers of Rowan University's new engineering program in 1995 to provide an engineering clinic sequence beginning in the freshman year and continuing each semester through the senior. While the sequence itself is described in the section which follows some key drivers for including clinic was the need to excite students to become life-long learners, to challenge them with open-ended real world problems that would enhance their desire to learn the problem solving methods that an engineering education offers and make them a more active participant in their learning process.

## 2. Engineering Clinics at Rowan University

The Rowan University College of Engineering was founded in 1996. This program was founded in order to enhance Rowan University's educational offerings for the benefit of students and the Southern New Jersey region. In 1998, the engineering curriculum incorporated the clinic sequence as part of its pedagogical approach to learning. The engineering clinic consists of an eight (8) semester sequence of courses that must be taken by all engineering students and accounts for 24 credit hours [1] of the degree requirements for each engineering major. The main purpose of the clinic program is to present the students with the opportunity of interacting and playing a key role in the development of an actual engineering project. This kind of

experience allows them to apply their current engineering abilities and develop new skills beyond the standard curricular offering they receive in their core engineering discipline [2]. Table 1 summarizes the courses and dominating themes for each semester [3].

**Table 1** – The Engineering Clinic Experience at Rowan University

| | Fall Semester | Spring Semester |
|---|---|---|
| Freshman | FEC I<br>Measurements | FEC II<br>Reverse Engineering |
| Sophomore | SEC I<br>Design w/written communication | SEC II<br>Design w/oral communication |
| Junior | JEC I<br>Sponsored Design or Research | JEC II<br>Sponsored Design or Research |
| Senior | SrEC I<br>Sponsored Design or Research | SrEC II<br>Sponsored Design or Research |

The structure of the engineering clinic intends to develop deeper the students' fundamental engineering skills by giving them an appropriate opportunity to apply those skills to real problems. A brief overview of the progression of content of each clinic course is explained below.

In the Freshman Engineering Clinics (FEC I and FEC II), students are introduced to fundamental principles of the four engineering disciplines offered at Rowan University [1]. During this set of courses, students are introduced to problem solving methods and to basic concepts such as error analysis and estimation. Students are also introduced to reverse engineering in order to understand the basic functioning principles of existing products. Students are also lectured on professionalism and ethics topics [4].

The Sophomore Engineering Clinics (SEC I and SEC II) are intended to improve students' both oral and written communication skills. Students are assigned to work in design projects that range from sustainability to biomedicine. Students are required to effectively communicate their project's progress through oral presentations and written technical reports. Sustainability projects offered in this clinic include the design of a wind turbine for power generation and solar photovoltaic assessments as feasibility studies.

Junior and Senior Engineering Clinics (JEC I, JEC II, SrEC I and SrEC II) provide students the opportunity to work in a real-world project as consultant, team engineer or research assistant. These real-world projects are usually presented as a combination of projects sponsored by related industry partners and faculty research interests [5-17]. Industry-sponsored projects have included research and design on sustainability, food processing, biomedicine and robotics among others [1].

Clinic teams are usually multidisciplinary. This experience entices students to improve their teamwork capabilities and to develop leadership and communication skills. The typical sequence of a clinic project is depicted in Figure 1 [18].

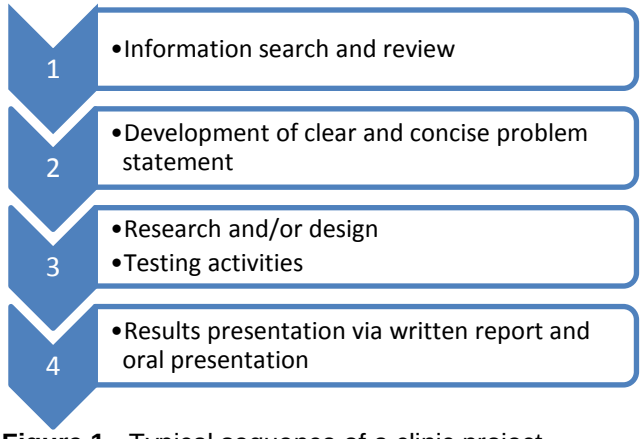


**Figure 1** - Typical sequence of a clinic project.

## 2.1 Engineering Clinics: A Tool to Teach Sustainable Design

Engineering in the 21st century requires consideration of current problems facing the world, for example: pollution, energy, and finite resources. To incorporate these aspects into engineering education, a novel approach is required. Rowan's clinical experience creates the environment where students can blossom as engineer, but more importantly have an education where multi-disciplinary issues such as sustainability can be incorporated.

With approximately 10 years of clinic accomplishments, Rowan University has become nationally recognized. It is with the incorporation of sustainability over the past 8 years that the College of Engineering within the University can continue to move towards global recognition for its work and graduates.

Even though there are many definitions of sustainability, the concept of sustainability that the university has followed is perhaps the most general one, where sustainable design allows this generation to perform living, working and consuming with a deep respect and consideration for the next generations to come [3].

The Engineering Clinic Program hopes to address as many projects as possible that incorporate sustainability into their main objective. Sustainable design projects offered in the engineering clinic program thus far have been focused on; renewable energy feasibility studies, energy efficiency assessment in buildings, wind assessments and photovoltaic system design.

## 2.2 Renewable Energy Feasibility Studies

A renewable energy feasibility study consists of the comprehensive assessment of a site in order to determine the strengths, weaknesses opportunities and threats presented by the environment and the resources available. These studies vary depending on the nature of the project, for instance, solar availability is assessed for the design of solar photovoltaic systems; while wind speed, wind direction and roughness of the terrain is evaluated for wind energy related projects.

Conducting a feasibility study is a preliminary step of all engineering endeavors. In the case of a sustainability project, where renewable energy sources are desired by the client or will be proposed by the engineering clinic team, the feasibility studies must be very robust and well thought out to withstand the additional scrutiny that often fall on new technologies. These studies are just one of the many tasks that junior and senior clinic students must tackle. However, during 2011 engineering students at the sophomore level, focused on completing a comprehensive feasibility for energy efficiency and solar potential. They spent an

entire semester, learning from both Faculty and peer presentations on the many things that must be taken into account when completing a building energy analysis and audit and conducting a solar feasibility and final photovoltaic system design..

Along with completing the important final deliverables for these real world projects these analyses both require and allow the students to familiarize themselves with many energy system components and their functions within the building under study. Along with the building components involved the students must also learn new skills specific to conducting the photovoltaic feasibility assessment. These include using a device named the Solar PathFinder [19]. This equipment enables the engineer to conduct detailed site shading analysis. Also, the students learned to enter their design data into software like PV Watts [20], to estimate PV system output and annual performance. Along with skills specific to photovoltaic layout, broader skills were also acquired.

## 2.3 Energy Efficiency Assessment in Buildings

Energy efficiency assessments are performed through energy audits. Energy audits consist of the evaluation and analysis of energy flows in buildings. These types of studies are intended to provide a clearer understanding of the overall energy consumption of a building and enable conservation recommendations to be made. Energy audits are laborious on all levels, but going through the process allows a student to connect directly to the building's energy flows like no other educational experience. The link from the individual energy consumer, to the total energy bill, is rarely connected with such clarity through any other process. It is known that the best way to ensure a positive change is through education, so the audit experience provided at Rowan is considered one of the best conceptual exercises offered. The insight received is carried with the students long after graduation, because once the consumption of an incandescent bulb is logged for a month, it will be less likely to leave it burning when a room is unoccupied.

We do not aim to over simplify the process of conducting an energy audit, but once the general approach is understood it can be applied on almost any scale. In the Spring 2011 semester a team of five undergraduates and a graduate student advisor conducted a semester long audit of a conference center located on Long Beach Island, NJ. This task certainly provided a set of small lessons that were specific to it; however the process of conducting the audit did not deviate from its basic implementation [5]. Table 2 outlines some of the projects that have been delivered through our engineering clinics that enabled students to develop these energy efficiency skill sets during the last eight (8) years.

**Table 2 - Clinic Projects on Energy Efficiency Audits & Assessment**

| *Year* | *Exemplar Energy Efficiency Assessment Projects* |
|---|---|
| **2011** | *Sophomore Clinic Building Energy Efficiency Analysis Design Experience*<br>*Energy Audits for Harvey Cedars Bible Conference, Long Beach Island, NJ*<br>*Energy Audits of Vineland Armory, Vineland, NJ*<br>*Energy Audit for Rowan University's Student Recreation Center (Rowan University)* |
| **2010** | *Energy Audits of Vineland Armory, Vineland, NJ*<br>*Energy Audit for Rowan University's Student Recreation Center (Rowan University)* |
| **2008** | *Municipal and Residential Energy Audits (SunTechnics)*<br>*Atlantic County Utilities Authority Headquarters Energy Audit (ACUA)*<br>*Fort Dix Energy Audit, New Hanover Township, NJ* |
| **2007** | *Municipal and Residential Energy Audits (SunTechnics)*<br>*Energy Audits of Farms and Public Buildings (NJBPU)* |
| **2006** | *Energy Audit Training & Renewable Energy Workshops (NJBPU)* |
| **2005** | *Energy Audits of New Jersey College Campuses (NJHEPS)* |
| **2004** | *Energy Audits of Rowan University Campus Buildings (Internal)* |
| **2003** | *Campus Energy and Environmental Audit (NJHEPS)* |

## 2.4 Wind Energy Feasibility Assessments

Wind feasibility assessments are intended to collect data in order to determine the feasibility of a wind energy installation at a specific location. Rowan University is a key cooperating partner in the New Jersey Anemometer Loan Program that provides interested citizens the equipment required to determine the suitability of wind power at their site.

The New Jersey Anemometer Loan Program was funded by the New Jersey Clean Energy Program (NJCEP) and the New Jersey Board of Public Utilities (NJBPU) in order to facilitate assessment of wind resources for residential, farm and commercial applications. This program intends to educate the public about the potential of renewable energies, specifically wind energy in the state. Clinic students were given the opportunity to complete the installation of the wind assessment system, comprised of mast, anemometer, anchoring and data acquisition units. Besides the initial labour, students provided a biweekly analysis of the collected data. Students were also able to gain valuable knowledge on the operation, maintenance and performance of a SODAR system, anemometers, data loggers, computer analysis software, wind manufacturer power curves and the relationship between power curves, wind resource and energy generation. This education resulted in completing assessment reports for consumers that assessed the economic viability of this type of sustainability investment at the location of interest.

Table 3 outlines some of the projects that have been delivered through clinics pertaining to wind assessments over the last six (6) years.

**Table 3. - Exemplar Wind Assessment Clinic Projects**

| *Year* | *Exemplar Wind Assessment Projects* |
|---|---|
| **2011** | *Freshman Clinic Wind Assessment Design Laboratory (Spring 2011)*<br>*NJ Anemometer Loan Program (NJBPU)*<br>*SJ Technology Park Wind Analysis*<br>*Evaluation of New Wind Vertical Axis Turbines for SJ application* |
| **2010** | *South Jersey Technology Park Wind Assessment*<br>*Mount Laurel MUA Wind Assessment* |
| **2009** | *Wind Turbine Feasibility for Johnson- Mathey*<br>*2 MW Wind Turbine System Siting and Wind Assessment , Sea Girt (NJDMAVA)* |
| **2008** | *2 MW Wind Turbine System Design, Sea Girt, NJ (NJDMAVA)* |
| **2007** | *NJ Anemometer Loan Program (USDOE, NJBPU)* |
| **2006** | *NJ Wind Working Group (USDOE, NJBPU)* |
| **2005** | *NJ Anemometer Loan Program (NJBPU)*<br>*NJ Wind Resource Assessments* |

## 2.5 Photovoltaic System Design

Rowan University is fortunate to be located in a state that offers some of the best renewable energy incentives in the country. Due to this fact the University incorporates photovoltaic (PV) system design into its curriculum and is able to offer it through various Clinic Projects [12-15]. Besides conceptual designs of residential roof top and ground mounted systems performed in the introductory freshman and sophomore clinics, junior and senior engineering students learn to perform detailed PV system designs for actual residential applications from outside parties (customers of the Center for Sustainable Design, faculty and staff at the university, and other inquiring persons). Some of the most notable project designs are the four (4) separate photovoltaic test beds that were also subsequently installed by the engineering students on several University buildings. All the necessary funding and materials for two of the projects were provided by Kaneka Corporation, the world's largest global manufacturers of thin-film

amorphous silicon panels. During the past two semesters students have conducted the preliminary design of a 10MW Photovoltaic ground mounted system on the University's West Campus. This system will provide a quarter of the University's yearly electrical energy demand once it is installed and serve as a good example of sustainable engineering for the surrounding region [15].

Clinics have also provided students the opportunity to analyze the performance of different solar photovoltaic modules by evaluating the operating characteristics (through the use of I-V and P-V curves) of these under certain conditions (different levels of shading and different tilt angle among others). Table 4 outlines some of the projects that have been delivered through clinics pertaining to the design of photovoltaic systems.

**Table 4. - Exemplar Photovoltaic System Clinic Design Projects**

| *Year* | *Exemplar Photovoltaic System Design Projects* |
|---|---|
| **2011** | *Freshman Clinic PV System Design Laboratory (Spring 2011)*<br>*Sophomore Clinic PV System Design Experience (Spring 2011)*<br>*1.65 kW Photovoltaic (PV) System Permitting & Construction Rowan Hall (Kaneka)*<br>*10 MW Photovoltaic (PV) System, Rowan University (Internal)*<br>*PV Module shading analysis (internal)* |
| **2010** | *1.65 kW PV System Design & Siting Rowan Hall (Kaneka - Japan)*<br>*10 MW Photovoltaic (PV) System, Rowan University (Internal)*<br>*PV Module shading analysis (internal)* |
| **2009** | *12 kW Photovoltaic (PV) System SJ Tech Park (SunTechnics)*<br>*PV System Design for NJDMAVA Headquarters*<br>*PV System Design for W.J. Doyle Veterans Cemetery* |
| **2008** | *3 MW Photovoltaic Power Plant, Falls Twp., PA (SunTechnics)*<br>*1 kW Photovoltaic (PV) System Installation - SJ Tech Park (Kaneka Solar)* |
| **2007** | *3 MW Photovoltaic Power Plant, Falls Twp., PA (SunTechnics)*<br>*Design of PV Systems for Municipal and School Buildings (Ocean City)*<br>*1 kW PV System Design & Siting (Kaneka Solar)*<br>*Performance Monitoring and Data Analysis (RU Team House)* |
| **2006** | *3-kW PV System Construction RU Team House (Internal)* |
| **2005** | *Design and Siting of 3-kW PV System at Rowan University (Internal)* |

## 3. Engineering Clinic Results

Life Long Learning is encouraged through the University's engineering clinic and curriculum and a desire to tackle the problems of today with the technology of tomorrow is instilled in its graduates. Graduates of the University have experienced great employment success with a number of them going into jobs with sustainability at their forefront [3]. With numerous recent graduates finding employment as solar engineers at one of the area's largest solar providers, another graduate is now taking his award winning Biofuel business plan and system design, to his native country of Haiti, to make and sell biodiesel made from the waste of an abundant native plant. Another recent engineering graduate student is an engineering involved in the design of a revolutionary inverter technology will reduce the cost of multi-MW photovoltaic systems by 30% or more. This technology is revolutionary based on its power rating of roughly five times that of current industry standards at a fraction of the cost and size [21]. While the above evidence is somewhat anecdotal, the ABET assessment the College of Engineering completed for its latest re-accreditation review includes more compelling statistics. As we surveyed alumni and their employers we were able to find that overwhelmingly the employers had stated that our graduates were well equipped to make meaningful contributions to their engineering staffs. Our alumni reported consistently that they were extremely well prepared in all ABET A-K criteria upon graduation. But perhaps the most convincing assessment result is the measurement of one metric of continuous or life-long learning that our engineering clinic is

so focused on achieving. In our 2006 survey of graduates for one of the engineering disciplines (electrical and computer engineering) for which one author is the ABET coordinator, we asked about their level of continuing education. Fully 53% of the ECE graduates had either completed or were completing either a Masters degree, MBA or PhD at the time of the survey [22].

As we increasingly face multi-disciplinary, global sustainability problems we more than ever need a generation of new engineers with sustainability skills and new perspectives. In the College of Engineering at Rowan University the engineering clinic sequence allows the flexibility within the curriculum that can focus content knowledge and real-world challenges into the learning experience of the young engineer. It is our hope that sharing this model and the types of project based learning experiences and results that these experiences achieve that other institutions may build upon the success we have been able to discover in this dynamic pedagogy.

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