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Entrepreneurship, Sustainability, and Design Projects

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Abstract

The School of Engineering at the University of Dayton has emphasized experiential learning for over twenty-five years. The evolution has gone from individual projects to team projects and from single-discipline to multidisciplinary teams. In the last five years, the percentage of projects related to design for the environment, sustainability, and renewable energy systems has approached about one-third of the capstone design projects. These projects have been further enhanced by the collaboration with the School of Business and the entrepreneurship program. Topics of innovation, entrepreneurship, and business planning have been introduced in the first-year innovative design course. In addition, some of the major capstone design projects include teams with students from engineering and entrepreneurship that address technical feasibility and the development of a business plan. This paper addresses our sustainability and entrepreneurship experiences over the last five years, covering applied aspects of sustainability in design education. In doing so, this paper concentrates on three areas. First, there must be a venue, or innovative engineering design culture, in which design and development projects can be implemented. Second, it is important that the appropriate resources be available in order to facilitate sustainable design. Finally, there will be a review of the types and scopes of these projects and the lessons learned over time. This final area will include the assessment methods to assure that we are meeting the needs of the clients and sponsors, both technically and through the development of business plans.

Introduction

There has been a growing emphasis on sustainable engineering and design. In its publication *Guiding Principles of Sustainable Design*, the US Department of the Interior and the National Parks Service define sustainable design as "a concept that recognizes that human civilization is an integral part of the natural world and that nature must be preserved and perpetuated if the human community itself is to survive. Sustainable design articulates this idea through developments that exemplify the principles of conservation and encourage the application of those principles in our daily lives" (1991).

The School of Engineering has emphasized experiential learning in its capstone design experience where projects are identified and implemented through the Design and Manufacturing Clinic (Doepker 2004). Using the Product Realization Process (PRP), over 500 projects have been implemented, sponsored by over 100 companies or entrepreneurs. PRP involves identifying a product development need, followed by the development of concepts, the performance of a decision analysis, a final design, and prototyping. This constitutes the proof of feasibility from a technical standpoint. Initial projects involved the design of components, machines, or processes. Projects were dominated by mechanical engineering majors and the four programs in engineering technology. To make the projects more multidisciplinary, we solicited other departments that had capstone design courses to join the clinic projects. In 2004, electrical and computer engineering joined the group. In 2006, we partnered with the management and marketing department (and entrepreneurship program) in the School of Business. Along with this later collaboration, multidisciplinary project teams entered the business plan competition and some projects included a formal business plan.

There has been a growing interest on the part of companies and individuals to sponsor projects related to sustainable design as it relates to alternate sources of energy, as well as renewable and clean energy. There is a culture of sustainability within which the design projects, and in particular the sustainable design projects, are implemented. In this category there are several topics. First there is the course sequence. For a number of years, the main course was a single capstone design course. As explained in the next section, more courses from beyond the first year have emphasized the design sequence. Finally, the newly renovated Innovation Center facility has become a location that is the focal point for nearly all design-related activities associated with sponsored projects.

Innovation and Entrepreneurship Throughout the Curriculum

The course sequence (Figure 1) can best be visualized by a flow diagram that shows the interrelationship between the stages of design process at various levels. In this figure there are four courses that span the four-year engineering curriculum.

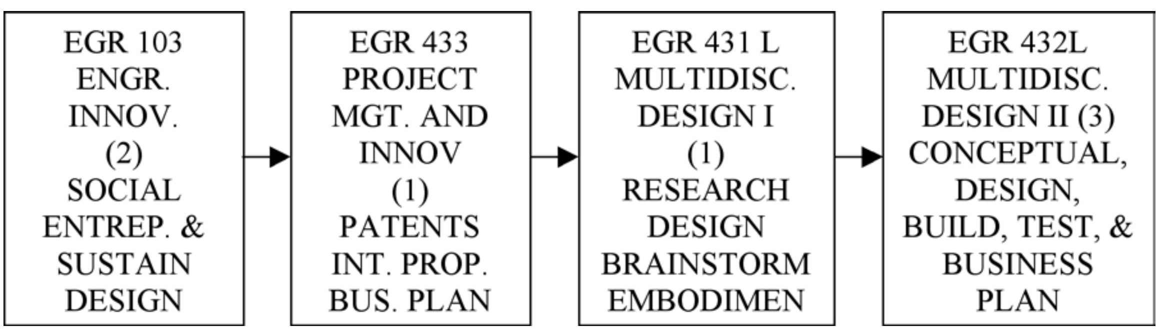

Figure 1. Design and Innovation Course Sequence

The first year experience

Engineering Innovation (EGR 103) introduces students to innovation and design. It incorporates a number of important aspects that will be of benefit the student throughout their engineering coursework. This is a required course for all engineering students; thus, everyone that graduates from the department will have been exposed to and experienced the design process and innovation. Although there is coverage of the importance of business plans in this course, this will be more formalized in the future when the students are presented with the opportunity to participate in the business plan competition. This class sequence also emphasizes social responsibility, environmental issues, and the product realization process (Doepker

2009). Early in the course, the students take the Myers-Briggs Test to determine not only their own personal traits, but also how to deal with others. A psychologist spends one class period reviewing the different characteristics of each type and how differences can enhance a team. This is followed by a fun team-building exercise.

An activity that was very successful was the Gummy Bear Project. This has been modified to include a Gummy Bear Boat or a Gummy Bear Car. In these design and fabrication challenges, each team is provided with a deck of playing cards, a roll of clear tape, scissors, and ten candy gummy bears. The bears must remain in the towers, cars, or boats throughout the event. In each of the designs, a hair dryer is used to try to topple the tower, or propel the car or boat. The tower that withstands the highest flow wins. The car or boat that moves four feet on the top of a table in the shortest time wins.

Another competition that has worked well is for the student teams to design, build, and test a cardboard chair. The students are provided with a 4 x 5 ft. sheet of cardboard and ten glue sticks. A box cutter, a yardstick, and a glue gun are used as construction tools. The chair must be at least twenty inches high, have a flat top surface, and be able to withstand a weight of 400 pounds (ten salt bags). All of the chairs that meet or exceed this standard are entered in a course-wide challenge. About 20% of the chairs met the design requirement. Several images of this challenge are provided in Figure 2.

These fun projects are used to stress the product realization process and foster team building. The students are asked to write a letter report describing their experiences, including questions such as: How did you arrive at a design? Was everyone involved? Did you experience all of the design phases? What would you do differently if you were to start over?

The PRP continues to be utilized in more detailed projects after this initial “small” project. In this case, a series of projects is generated by the faculty that exemplify the course’s goal of social responsibility and environmentally friendliness. The designs developed in this segment result in the building of models but short of being prototypes. Projects have included a self-sustaining cabin, the use of photovoltaics for pumping water for irrigation in Togo, and a solar collector that would follow the sun.

As described earlier, the first-year engineering innovation class emphasizes the product realization process, teamwork, and written and oral communication. The major project covers about six weeks, and most of the projects are centered on social entrepreneurship and sustainable design. One project involved the design of an assistive device for stocking shelves by an individual that was paralyzed on one side of his body. Another concentrated on the design of a cabin that could approach energy independence. Because of the total number of first-year students, there are about seven sections of the class, with about twenty-four students in each class. This means that there would be six teams with four or five students on each team in each class. One successful project involved the design of a device to move a flat plate (photovoltaic) that

Figure 2. Cardboard Chair Construction (left) and Testing (right)

would remain nearly perpendicular to the direction of the light from the sun.

These designs typically incorporated a device that was powered by the transfer of a mass from one point to another by means of gravity. This motion in turn produced motion of the mechanism that moved the solar panel.

The conclusion of the project requires oral presentations and a written technical report. As in previous studies (Terpenny et al. 2007), the outcome of this class is that students believe they have a better appreciation of the design process and the engineering profession. This prepares them for other courses in the curriculum and for being a practicing engineer, where team projects are the norm.

Upper level design

As part of the design sequence, a new course, EGR 433, has been implemented to emphasize innovation and entrepreneurship. Topics include project management, time value of money, cost estimating, business plans, and intellectual property. This course does not emphasize sustainability but has been an asset to sustainability projects because of the large number of sustainability entrepreneurs that need business plan support.

The Product Realization Process (PRP) (Doepker 2004; Pugh 1990) is the approach used in all the design project courses (EGR 103, 431 and 432). Nearly all of the projects have an external client, especially those that are later in the curriculum. The major areas of the PRP are:

1) Establishing the need with the client.
2) Developing the specifications and writing a proposal. This includes the functional requirements, design requirements, and design criteria.
3) Based on these guidelines, the individuals generate concepts and bring their ideas to the team for consideration. The top candidates undergo a decision analysis.
4) The decision analysis establishes the embodiment design. A feasibility analysis and feasibility tests are performed. In Figure 1 (above), this is the end result in the one-credit-hour class. The project may be continued (in EGR 432L) where the final design, build, and prototype testing occurs.
5) This embodiment design is followed by the final design, analysis, and testing.
6) The final step is the implementation of the design into the system, or perhaps will result in the design being combined with a business plan to create a new product through entrepreneurship.

The above process has been enhanced in the curriculum with the partnership between the School of Business Administration (SBA), the Management and Marketing Department, and the Entrepreneurship Program. With the strong foundation that has been built with over a decade of industry-sponsored projects in engineering, and an entrepreneurship program that is ranked fourth in the country by *The Princeton Review,* a strong collaboration has been established. We are continuing to strengthen this alliance through multidisciplinary teams that design and build products, which, along with a strong business plan, can be the basis for an entrepreneurial enterprise.

Innovation Center

The infrastructure

It was decided that an Innovation Center would be built in addition to the already successful Design and Manufacturing Clinic. The clinic and center have so far implemented over 500 projects with nearly 100 clients. This was not only an administrative effort, but also involved a substantial investment in the renovation of part of the first floor of the engineering building. There are a number of major areas:

1) The design studio is the heart of the facility, where students come to collaborate with other members of their teams. Several views of this are shown in Figure 3. The studio includes computers and projection equipment.

2) Adjacent to the design studio is the Product Development Lab, seen in Figure 4. In this lab, students can build models and prototypes using hand tools, bench top tools, and instruments including sensors, transducers, and recording equipment.

Figure 3. Innovation Center Design Studio

3) The team meeting rooms are adjacent to the design studio and the product development lab. These rooms are used when teams need to have more space than in the studio, or when they need to meet outside of class. They are frequently used when clients visit and the teams need to be away from the movement and noise of the studio.

Figure 4. Emerson Climate Technologies Product Development Lab

4) There is a large conference room in the complex that can comfortably hold twenty-five people. This is the room used for formal presentations and distance communication.

5) The team projects room is where project hardware can be stored before, during, and after assembly takes place. Materials are frequently stored in this room from one semester to another when a project starts in the one-credit class and is finished by the same team of individuals in the next semester.

6) The office area is adjacent to the large conference room and houses the offices for the administrative assistant, director, coordinator, and adjunct faculty.

Innovation and entrepreneurship

With the capstone design projects becoming more multidisciplinary, major changes took place in the time span from 2006 through 2008. First, we formed an external advisory committee, composed of practicing professionals from the finance industry, small businesses, entrepreneurs, engineers, technical societies, other universities, and existing clients and sponsors. At the first committee meeting, it was established that the first item of business for the new center was to develop a strategic plan. Representatives from the Entrepreneurship Program, School of Law, Retail Marketing Sector, an Engineering Executive in Residence (former CEO), and the Director of the Innovation Center spent six months developing a SWOT analysis and strategic plan, as well as the vision, mission, and goals. This committee meets periodically to determine the progress in achieving our goals.

Another major achievement was the development of proposals to the Kern Family Foundation to obtain a KEEN (Kern Educational Entrepreneurship Network) grant. This not only provided the focus we needed to expand the mindset of engineering students and faculty, but also a venue where we could learn from cohort institutions about the methods that had worked to establish this mindset.

The experience and assessment

Over the past thirteen years, the number of projects has grown from eleven per year to eighty. This is because of the increase in the number of students in mechanical engineering and the increase in the number of departments participating in the Innovation Center and the Clinic. The number of students involved with the senior capstone design experience in a one-year period has grown from sixty-five in 1996-97 to 350 this past academic year.

At the conclusion of each project, the industry mentors are asked to evaluate the projects and the student performance. Over the past six years, 76% of the clients/mentors have said that the results have been significant for them. Twenty-three percent thought the results would be moderately helpful. A major area of interest has been for the question that asks at what level the goals have been met. Twenty-four percent said the goals were exceeded, while 62% said the goals had been met. Thus, 86% felt that the goals were either exceeded or attained. Thirteen percent thought that they were nearly met, while 1% said that they failed to meet the goals. This can be seen in summary form in Table 1.

Year	Exceeded (4)	Attained (3)	Nearly Met (2)	Failed (0)	Score
03/04	6	26	2	0	3.1
04/05	3	17.5	5	.5	2.8
05/06	7	19	6	1	3.0
06/07	14	37	9	2	3.1
07/08	11	26	6	0	3.1
08/09	20	24	2	0	3.3

Table 1. Sponsor Assessment – At what Level Were Goals and Deliverables Achieved?

Emphasis on Renewable Energy and Sustainability: Projects

Multidisciplinary Design I, EGR 431L: Solar Thermal Panel

The first course in the upper level is a one-credit-hour junior/senior-level design class, Multidisciplinary Design I. This course introduces the Product Realization Process (PRP) in detail and requires that student teams identify needs and specifications, develop conceptual and embodiment designs, conduct a decision analysis, and perform feasibility analyses and testing. If these designs show significant potential, they are carried over to the three-credit-hour class, EGR 432L. In recent semesters, about 40% have been related to sustainability and renewable energy. This has included wind turbine location, solar thermal for heating water, photovoltaics, and the implementation of ground-source heat pumps.

An entrepreneur has sponsored a project to design solar thermal panels to heat water for home use. These panels could be a part of a wall panel or could be installed on a roof. One criterion is that it should be easily transportable so it could be sold at a hardware store and installed by a semi-skilled homeowner. A sketch of this device is shown in Figure 5. The pump could be powered by normal electricity from the grid but the student team (Berquist et al. 2009) decided to use a photovoltaic panel. In this design, the water would move through the panel, be heated by the sun, and drain into a tank similar to a hot-water heater. This tank would become a heat exchanger in which the primary low would be from the solar thermal panel and the secondary coil would transport the normal household incoming water from approximately 55 degrees Fahrenheit to a higher temperature. This water would be introduced to the hot water heater at a temperature nearly that of the normal hot water tank, thus reducing energy consumption because of the reduced need from the utility grid.

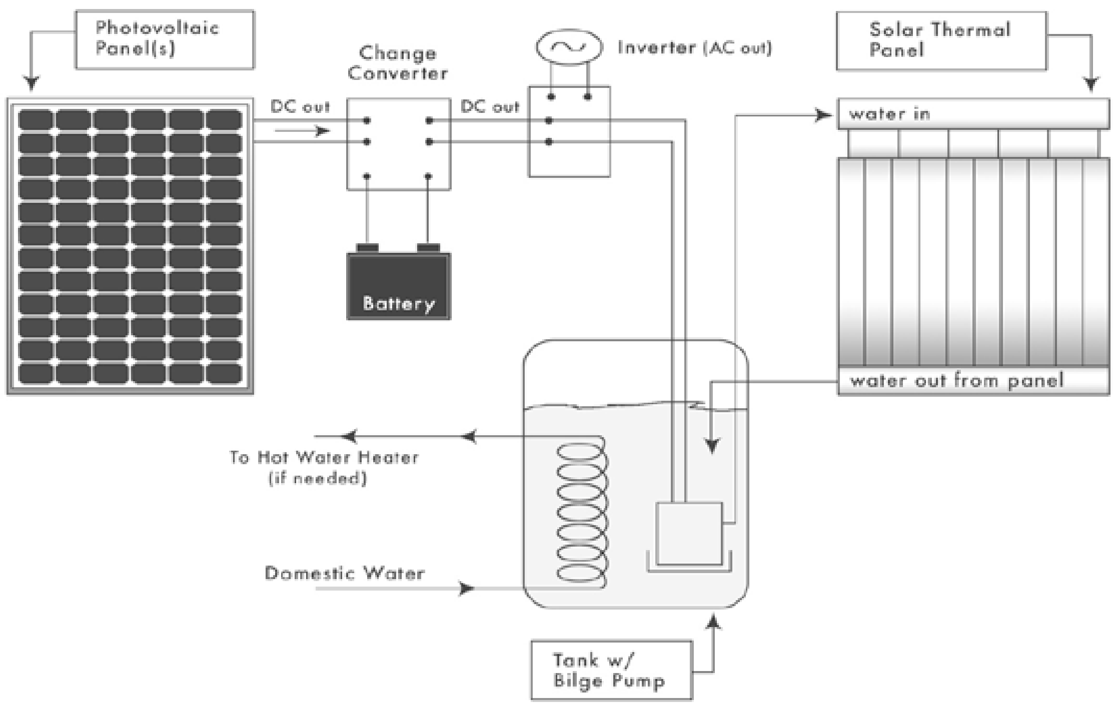

Figure 5. Schematic Diagram of a Solar Thermal System

Multidisciplinary Design I, EGR 431L(continued): Geothermal Aquifer

Another EGR 431L project was sponsored by a real estate entrepreneur working with numerous architects to revitalize downtown Dayton. There are ten buildings under consideration for renovation, eight of which are within a two-block area of a large open lot and a park. This block is approximately 2,000 feet from the banks of the Miami River. Since the city sits on the top of this aquifer, the water level in the aquifer is approximately the same as the river. Thus, one only needs to drill down twenty feet to reach the water level of the aquifer. The aquifer location is shown in Figure 6.

The developer approached the Innovation Center with the idea of using the water supply from the aquifer to provide a constant flow of water to a plate style heat exchanger. This flow of water from the aquifer is defined as the primary flow. The secondary flow is heated or cooled in the heat exchanger and is the supply to the heat pumps. The primary side water cannot be used for this because of the high acid content of the flow water. The student team developed a system similar to that shown in the schematic diagram of Figure 7 (Goodyear et al. 2009).

Since this project was initiated in the one credit course, the student team developed conceptual designs and moved to the embodiment design phase. The team has been communicating with many constituencies within the city to conduct research and make estimates regarding the cost of such a system. It is estimated that it will require drilling four wells, three of which will be in use at any one time. The wells, plus the cost of the pumps, will range from $100,000 to $200,000 for each system. Based on an earlier venture of this type with a condominium complex, it was found that water must be returned to the aquifer at a point greater than 100 feet, or the inlet ground water will be compromised in temperature. It is estimated that for this venture the water could and should be returned 500 feet from the inlet. This project will carry on to the fall term in the three-credit class (EGR 432L), at which time the size and cost of the flat plate heat exchangers will be determined.

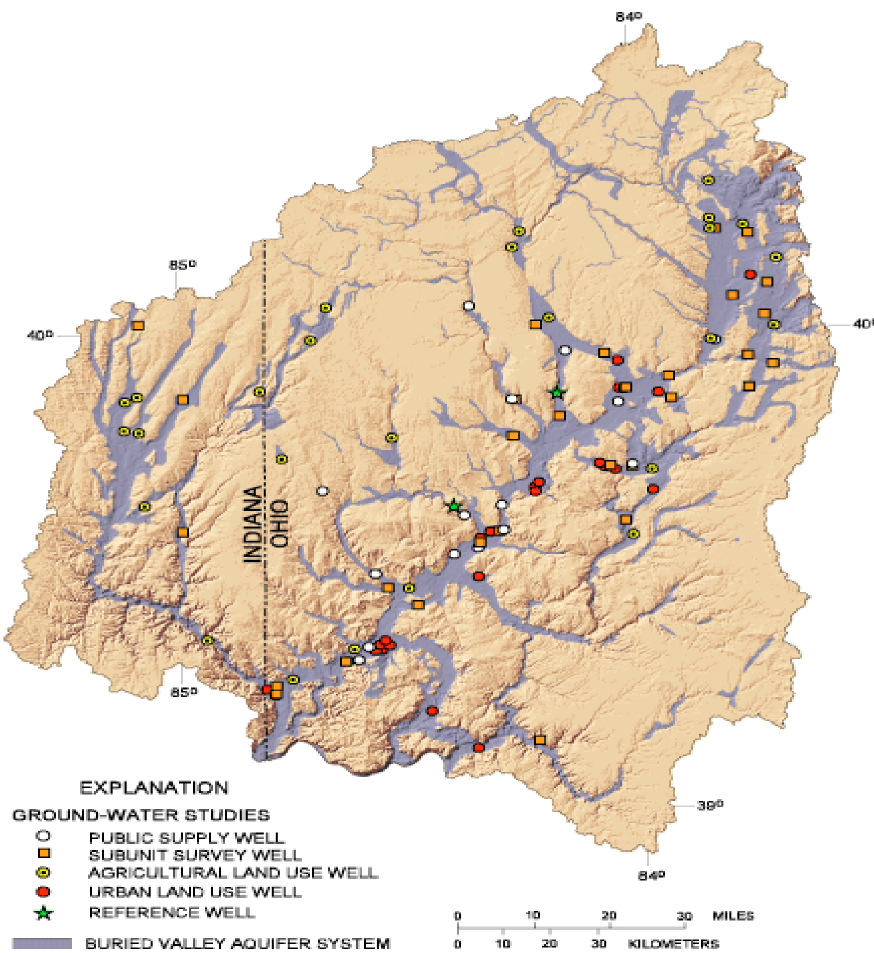

Figure 6. Southeast Ohio Aquifer (USGS)

Multidisciplinary Design II, EGR 432L: Industrial Energy Assessment

A major corporation requested that a student team evaluate the energy conservation and sustainability aspects of one of its major manufacturing facilities. The managers within the company realized that improvements were necessary and asked that the team evaluate their practices and make recommendations for an approach to address more efficient energy practices. The student team (Ahmad et al. 2009) addressed this over two semesters and developed the following:

1) Researched and evaluated tools for environmental management systems (EMS) and made recommendations for packages to use.

2) Made detailed recommendations within their final report that evaluated environmental policy. This included an evaluation of recent policies of the new national political administration. The team addressed energy policies, carbon trading markets, tax credits, and renewable energy certificates.

3) Evaluated energy assessment organizations and made recommendations based on the needs of the company and their criteria.

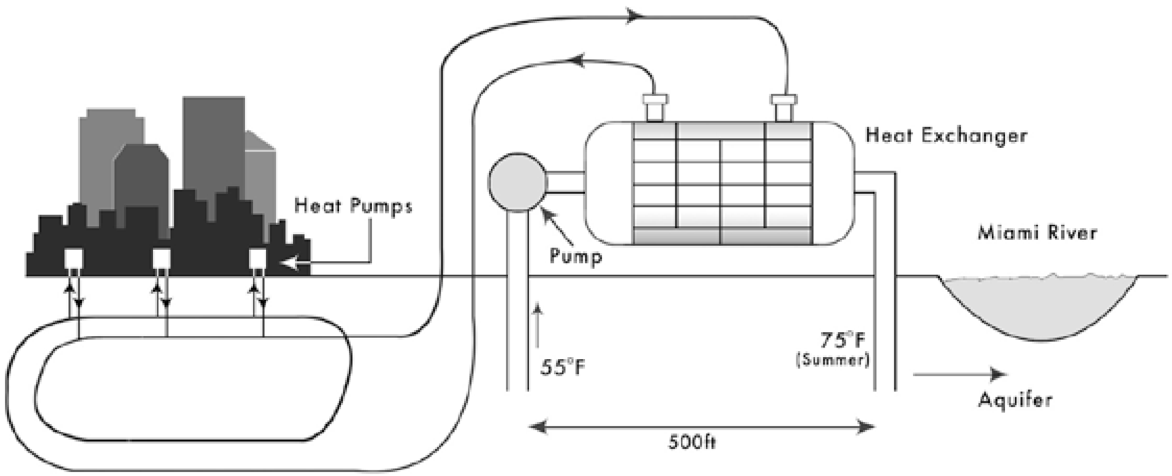

Figure 7. Schematic for the Geothermal Source for Heat Pumps

Multidisciplinary Design II, EGR 432L: Transportable Solar PV System

A major supplier of efficient energy systems requested that a student team design a transportable photovoltaic system. This system could be moved to remote sites that may have experienced power outages or in a region that does not have existing power from the grid. This involved the design of a trailer and a grouping of photovoltaic panels, electronics, and batteries that could be transported to remote sites. This was a two-semester project culminating in a system that can be put on a trailer. In the first semester (EGR 432), students evaluated conceptual designs and the resulting embodiment design. In the second semester, students addressed the final design and built the electrical and structural systems. The system was assembled in the lab, the results of which were compared to the design criteria. The team researched (Hogan et al. 2009) the needs for such sites, such as the power required to recharge tools and the power to operate machines and provide power to appliances. Figure 8 shows the components that were assembled and developed in the lab prior to installation on the structural frame.

Figure 8. Components for a Transportable Photovoltaic System

Emphasis on Innovation, Intrapreneurship, Entrepreneurship, and Sustainability

An evaluation of the capstone design projects over the past year has shown diversity in the types of projects that have been implemented. Traditional projects are those that involve ideation and innovation to solve problems in a manufacturing or industrial environment. These include the design of a manufacturing workcell or a test stand to improve accuracy or time to test a product. This is shown as the first row in Table 2.

Table 2. Innovation, Intrapreneurship, Entrepreneurship, and Sustainability

The entrepreneurship projects are those sponsored by individuals outside of a corporate environment where the possibility existed for business plans and the proof of technical feasibility. These projects could be both conceptual as well as a final design with a prototype. In most cases, the entrepreneurs consider seeking a patent and then move on to seek venture capital. This is somewhat problematic, since we do not have an incubator to shepherd the process to a final business.

The intrapreneurship projects are those that involve innovation and new product development, but in a corporate environment. In these cases, the corporations will identify the individuals on a team as a part of a patent when a final patent is sought.

Resources

The key ingredients for all of the project teams include available resources. Some of these resources are:

- Availability of faculty mentors, some of who are a part of the Industrial Assessment Center that provides no-charge energy and waste reduction assistance. These faculty members also have a vision that has expanded our programs to include an MS in Renewable and Clean Energy.
- A design studio, small meeting rooms, and large conference room for teams to meet to discuss and

brainstorm ideas.

- A prototyping lab that includes facilities for building models and developing experiments. From a sustainability standpoint, this is equipped with photovoltaic panels, solar collectors, and the electronics necessary to build energy-efficient systems. We have been fortunate to have clients and sponsors who have contributed to the special equipment required for designing renewable energy systems. These have formed the building blocks for students of all levels to explore renewable energy.
- Industry mentors that are experienced in all forms of renewable energy and sustainability initiatives.
- As the result of having a world-class Industrial Assessment Center, there is a high level of interest in energy systems, not only among the faculty but also among the student body. Courses in design for the environment, energy-efficient manufacturing, and designing thermal systems prepare the students for these capstone-level projects.

Conclusions

1) The EGR 103 class was implemented for the first time in the 2008-09 year. Several projects were attempted for the major project. It was found that those involving sustainability were the most liked and most successful. Photovoltaics, thermal solar, and other projects of this nature were easy to implement because of the simplicity of the systems. They are at a level that first-year students can understand. The cardboard chair project had the greatest success. The sequence of the smaller project followed by a larger project was a plus.

2) The two-semester sequence of EGR 431L and 432L was good for sustainability projects. Research and conceptualization could be implemented in the first class, followed by final design, build, and test in the second project.

3) Sustainability projects are popular with small business (photovoltaics, solar thermal, etc.), while larger companies are interested in energy savings. Nearly 40% of our projects are related to sustainability.

4) Having the resources, equipment, and mentors has provided the support needed for successful project. Qualified faculty are helpful during brainstorming sessions. Equipment is needed for feasibility testing and analysis. If it were ordered during a project, there is a high probability it would not be available for a long enough period to help the student teams.

5) It is recommended that we continue to address the interest in mechanical and electrical engineering to determine the level of interest in sustainability so that this can be marketed to the potential clients.

6) We are beginning to achieve our vision of becoming a premier undergraduate program that emphasizes both entrepreneurship and technical excellence.

7) The lack of an incubator for entrepreneurs has hampered the development of manufactured products and the formation of actual businesses.

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