Integration of Sustainability in a Multidisciplinary Engineering Department

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Integration of Sustainability in a Multidisciplinary Engineering Department

As a small department with two unique engineering programs, we face challenges in offering programs efficiently and in introducing new topics of importance in engineering. Our solution has been to take a multidisciplinary approach to each program and to new topics.

We also embrace multidisciplinarity as a goal in itself. We stress to students that they are engineers first, with a disciplinary specialty as a second consideration. Some engineering jobs require a specific disciplinary or subdisciplinary focus, but many other engineering jobs require broadly educated engineers; we seek to prepare our students for those broader jobs.

One approach we have taken to promoting multidisciplinarity is through the integration of the topic of sustainability into our programs. Sustainability involves products, processes, and practices that meet the needs of current generations while preserving the ability of future generations to meet their needs. The topic is relevant to and requires the use of many engineering disciplines. It also requires the integration of engineering knowledge with knowledge of other disciplines outside engineering.

Our programs present students with topics in sustainability throughout the curriculum, so the students start with awareness and move to knowledge and application. In this paper, we present examples of how we move students to these different levels in each year of the program using activities in many courses, from introduction to engineering through the senior design project.

We conclude with our recommendation that other engineering programs that want to increase multidisciplinarity should consider the framework of sustainability as a way to move toward that goal. The topic of sustainability can move an engineering program toward increased integration of engineering disciplines as well as toward increased integration of engineering with other fields.

Multidisciplinary nature of our programs

Our Department of Engineering at Colorado State University-Pueblo (CSU-Pueblo) offers two undergraduate degrees, the BS in engineering with a mechatronics specialization and the BS in industrial engineering. Because the first one is a BSE degree, it is designed to combine many disciplines in engineering; the specialization in mechatronics means that the program is strongest in electrical and mechanical engineering. The BS in industrial engineering is multidisciplinary in the sense of integration of engineering with the social sciences and business; industrial engineers must consider the people in any system and the industrial engineering major is the closest engineering major to a business major, while still being a strong engineering major.

Because of the nature of our programs and the size of the Department (seven faculty members), the faculty members have varied backgrounds. Faculty in the department have degrees in electrical, industrial, mechanical, and systems engineering, as well as in mechatronics, industrial automation, engineering management and systems engineering, and mathematics. The nature of the programs and the size of the Department also lead us to stress efficiency in offering these programs and the two programs have 16 engineering courses in common, in addition to required

math, physics, English, and speech communication courses. Each degree has seven unique engineering courses. We also have MS degrees in mechatronics and industrial engineering and some courses are dual listed at undergraduate and graduate levels, leading to more efficiency. Finally, we have recently begun a MS degree in railroad engineering, which introduces more multidisciplinarity to the Department since railroad engineering builds on civil, electrical, industrial, and mechanical engineering.

The seven faculty members work together on all curricular issues, as shown by the fact that we are all coauthors on this paper. We defer, of course, to the disciplinary expertise of our colleagues, but we all feel responsible for all the programs. Thus, regardless of disciplinary background, each has learned a great deal about the other engineering disciplines.

Multidisciplinarity of sustainability

Sustainability involves products, processes, and practices that meet the needs of current generations while preserving the ability of future generations to meet their needs. Sustainability has three major components, sometimes called people, planet, and profit, as explained in more depth by Figure 1. Thus the topic of sustainability is inherently interdisciplinary, both within engineering disciplines and in connecting engineering to disciplines outside of engineering.

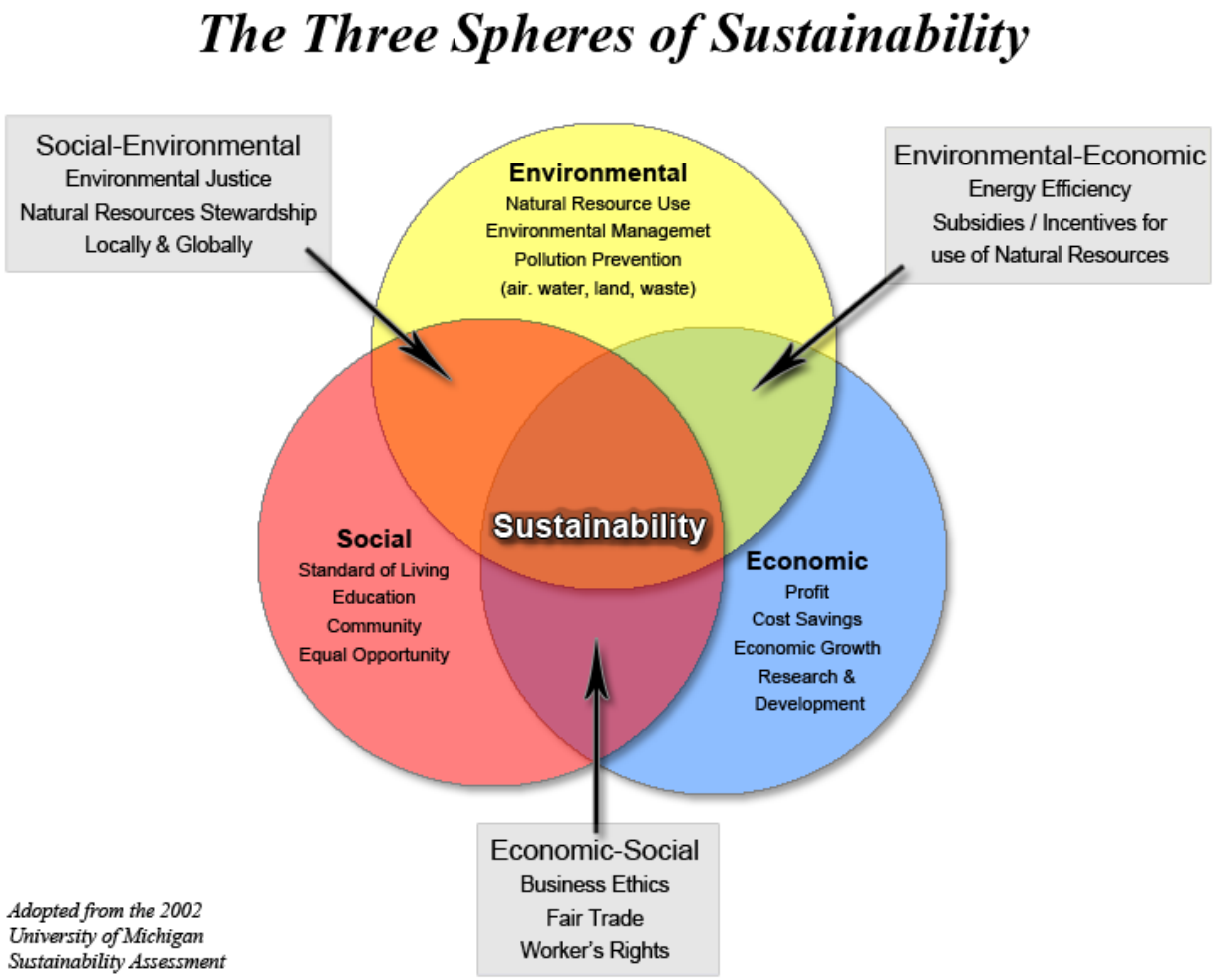

Figure 1: The three components of sustainability.
Source: http://www.vanderbilt.edu/sustainvu/who-we-are/what-is-sustainability/.

Within engineering, the civil engineering field can probably claim the earliest acknowledgment of the issues of sustainability (environmental engineering and green building, as two examples), but considerations of sustainability are now strongly present in all engineering. ABET's required program outcomes (items (a) through (k)) include two that deal directly with sustainability:

> (c) an ability 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, and
> (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context. (Source: http://www.abet.org/eac-criteria-2014-2015/)

Criterion (c) explicitly mentions sustainability. Criterion (h) refers to the economic, environmental, and societal context, corresponding to the three components of sustainability. Other criteria (such as (f) an understanding of professional and ethical responsibility and (j) a knowledge of contemporary issues) also relate to sustainability.

Outside of engineering, working toward sustainability requires, for example, understanding of environmental science, economics, psychology, and political science. Interestingly the Venn diagram in Figure 1 does not contain the word "engineering" but we believe engineering permeates the diagram.

Other engineering programs have used topics in sustainability as an approach to multidisciplinarity. As examples, in papers previously presented in the ASEE Multidisciplinary Division:

- Chen *et al.*[1] describe the development at Miami University in Ohio of a multidisciplinary course on energy policy.
- Lenczewski *et al.* [3] describe the development at Northern Illinois University of three degree programs (including one in Energy and Environmental Systems Technology) involving a governing board of 15 faculty members from 13 departments.
- Liao *et al.* [4] describe the development of a new multidisciplinary course on smart grids.
- Stansbury and Towhidnejad[5] describe using the EcoCAR challenge in a capstone design course in computer and software engineering.

The work we report here differs in scope from these papers. First we have incorporated *more* multidisciplinary connections by using the broad topic of sustainability. Second we have incorporated the topic of sustainability into *more* courses throughout our programs.

Sustainability in our engineering programs

In 2011 CSU-Pueblo received a five-year $4.3 million grant from the US Department of Education to create the PROPEL center to help STEM programs incorporate sustainability, incorporate service learning, strengthen the use of educational technology, and improve articulation with community colleges. The PROPEL center has brought many positive changes to CSU-Pueblo, including the creation of a new campus wide minor in sustainability.

The engineering faculty embraced the goal of incorporating sustainability throughout the engineering curriculum. We have proceeded by using different strategies at the different levels of the curriculum:

- First year courses. Increase students' awareness, knowledge, and positive attitude toward sustainability by exposing them to information about sustainability using examples throughout engineering.
- Second year courses. Use the topic of sustainability as a strategy to motivate students throughout the engineering science classes.
- Third year courses. Use exercises and projects in which students apply engineering knowledge to topics in sustainability.
- Fourth year courses. Ensure students' knowledge of sustainability in the senior seminar and require that students consider sustainability in senior design projects.

In each year we continue the previous strategies and add more, so that by the senior year, the students find sustainability a natural part of engineering and a natural view of the world. Explicit instruction on sustainability is done as "bookends" with an introduction to the topic in the first year and more in depth instruction in the senior seminar. In between, we do not stress the word

"sustainability," but simply use sustainability topics throughout the courses. We now give examples of changes made in specific courses that demonstrate these strategies.

We have added topics on sustainability in first year courses including introduction to engineering, engineering computer programming, and engineering graphics. In the introduction to engineering course, we include a module on sustainability (with pre and post tests of student knowledge and attitudes). Material from our city's sustainability plan is used as well as information on the National Academy of Engineering's Grand Engineering Challenges; of these 14 challenges, the first six (such as, provide access to clean water) directly relate to sustainability. Students use an online calculator to compute their carbon footprints measured in the number of earths that their lifestyle consumes (a lab session that often results in shock among the students). Students use myGrid boards to explore the operation of solar panels in a power grid. A programming assignment requires students to do calculations to project population and farmland into the future. Using the sustainability module in SolidWorks, students in the engineering graphics class compare the impacts of different designs based on the material used, the place of manufacture, and the place of use.

While the first year emphasizes awareness, in the second year courses, we strengthen and build on awareness by having students apply the knowledge they are gaining to engineering problems associated with sustainability. During the sophomore year students in both programs take courses in mechanical and electrical engineering, as well as courses in their selected specialty. In the sophomore introduction to industrial engineering, students work in teams to design and create products from trash that someone might buy: products have included a stuffed toy made from plastic bags, a cardboard home, a water bottle greenhouse, and home insulation made from shredded water bottles. In the statics class, forces are calculated on a wind tower. The probability and statistics class analyzes data on income distribution, deaths from injuries and combat in war, drilling temperatures using a green lubricant, and wind speed.

In the junior level courses, students take more courses in their selected specialty. Exercises and projects in sustainability reinforce the multidisciplinary nature of engineering. The engineering economics course examines the economics of recycling, a course on production planning designed a factory for fuel cells, a team of students did research on the design of a Materials Recycling Facility for our city, and a course on simulation has homework involving the design of a faculty to reduce energy use. These projects and exercises remind students that success in engineering requires the use of many engineering disciplines and the integration of engineering knowledge with knowledge of other disciplines outside engineering.

In the senior year we engage students more explicitly on the topic of sustainability. After taking several courses separately in the junior year, students from the two engineering majors take the senior seminar and senior project courses together. In the senior seminar, the sustainability expert from the PROPEL staff provides an overview of sustainability. Germanium is used to illustrate calculations needed to compute a sustainable use of a resource. We again use the 14 NAE Grand Engineering Challenges to illustrate the multidisciplinary nature of engineering. We use a test developed at The Ohio State University and the University of Maryland as a pre and post test of students' knowledge of sustainability. [6]

In the senior design project, each team must include an evaluation of the impacts on sustainability. Table 1 shows the rubric we use to evaluate that portion of the project report.

F	D	C	B	A
Not mentioned	Mentioned only as a part of another objective	Section includes a single sentence	Section consists of a single paragraph but is not integrated into the project	Section consists of one or more paragraphs. Sustainability aspects are documented and integrated within the project

Table 1. Rubric for grading sustainability portion of senior projects.

While this description shows that we use similar strategies over the four years of each program, the approaches do differ between the majors. Since industrial engineering is about efficiency and already considers impacts on humans, the approach to sustainability in the BSIE stresses those aspects. Since mechatronics involves controls, sustainability can be implemented through more efficient energy consumption. Material selection is applicable to both programs and is considered in the materials science and engineering course required in both programs.

We also use strategies involving the student groups (ASME, IEEE, IIE), where students work on projects. The Colorado Space Grant supports projects on the biosphere and on the Sabatier reaction, promoting students' understanding of the energy and atmosphere cycles necessary to support life on Earth and on Mars. We do not have any of the traditional engineering honor societies; instead we invite all seniors to join the Order of the Engineer. The students notice early that faculty members wear the ring of this Order, and they look forward to the ceremony, in which all recite the Obligation of the Order of the Engineer, including the acknowledgement "that my skill carries with it the obligation to serve humanity by making the best use of earth's precious wealth."

Our focus on sustainability extends to Master's thesis topics which have included: sustainability in hospitals, a simulation of the adoption of sustainable practices in a community, the siting of solar panels, a simulation of the effect of policy changes on CO2 emissions in Colorado, and the design, construction, and life cycle analysis of a solar tricycle.

Future work

We continue to add more examples of sustainability in every engineering course. For example, force and moment determination for solar panel support structures is being added to the statics class.

We already have 6.2 kilowatts of solar power that were installed on our building in 2006 (and a 1.2 megawatt installation elsewhere on campus) and, in a very exciting development, we will be adding a 10 kilowatt wind turbine near our building. Projects relating to the wind turbine will be incorporated into team projects in the engineering economy, manufacturing processes, and project management classes. The engineering economy project involves calculation of the

economic merit of the project considering avoided electricity costs and renewable energy credits. The daily energy production will be estimated in 2014 and collected on line in 2015. In project planning and control, students will document the activities needed to erect a working turbine and construct CPM/PERT charts to determine and estimate the critical path. In the manufacturing processes class, teams will review the processes needed to manufacture each component of the turbine.

We are exploring the addition of a new specialization in sustainability in our BS in Engineering. We also plan to study more carefully the development of our students' identification as an engineer and as a particular type of engineer, from the first year through graduation and employment. Because we encourage our graduates to link with us on LinkedIn, we will be able to study the type of jobs they take.

What we have learned

Since our programs are already multidisciplinary, we continue to learn about how to have a Department of Engineering, that is, a department not devoted to just one engineering discipline. A multidisciplinary approach requires that all faculty members have multidisciplinary knowledge and a multidisciplinary attitude. Our sense of shared responsibility means that we continue to learn from each other about our different disciplines. No one can stay in a disciplinary silo.

Some topics in sustainability (as examples, income distribution and economic justice, the effect of CO_2 emissions by humans on climate change) have political implications and can be controversial. We learned that we experience very little push back from students. Presenting sustainability in the context of the engineering profession lends it credibility. For example, the sustainability focus in the NAE Grand Engineering Challenges certainly shows that sustainability is now mainstream engineering. Without calling attention to sustainability, we incorporate applications of sustainability in a way that conveys to our students that sustainability is obviously and without controversy part of engineering.

Sustainability is just one way to achieve multidisciplinarity in engineering and we use other themes as well. We use design as an integrating idea in our curriculum, building up students' ability to do design. We stress community engagement as a way to stress the professional obligations of all engineers.[2]

Many resources are available to help faculty members learn about sustainability. While we have the advantage of having staff at the PROPEL center to help us learn, we have also found that vendors, ASEE, and the Association for the Advancement of Sustainability in Higher Education are rich sources of information. Vendors are creating material to support the teaching of sustainability. Vendor workshops and conversations with vendors at the ASEE conference have helped us identify technology and teaching materials that we can relate to sustainability. For example, myGrid by Elenco is a mini system that interfaces with the NI myDAQ to help students learn about the components of a power grid.

Local companies also support our education efforts in sustainability. One local plant, United Technologies Corporation (formerly Goodrich) hosted a class for an extended presentation on their efforts in sustainability. We also have a plant that manufactures towers for wind turbines. A railroad research organization, TTCI, emphasizes the energy efficiency of rail transportation.

Our involvement in sustainability has reaching a tipping point where we find that when creating homework, class projects, senior projects, and MS thesis topics, examples relating to sustainability come naturally. We are starting to see the effect in the projects students select for senior projects, with two out of seven projects this year relating to sustainability, in particular, aquaculture and the Material Recycling Facility in our town.

Conclusion

Sustainability is, in many ways, not a new topic in engineering at all. Engineering societies and the model code of ethics have always stressed components of sustainability, for example, with the injunction to hold paramount the safety of the public. Engineers have always been concerned with the choice of materials, the use of energy, safety, and proper disposal of waste. The recommended ceremony for the Order of the Engineer includes a recommendation that the new members of the order contribute to their communities by becoming active in governing bodies and civic organizations.

But we find that the framework of sustainability adds to these traditions; it adds a reminder to consider the three major components (people, planet, and profits), it adds a useful word to encompass the many obligations of the engineer, and it adds a positive way to interact with other disciplines. Our university's procedures required that the proposal for the new campus wide minor in sustainability had to originate in one department; we are proud that the Department of Engineering is the home department for this minor. The leadership role of engineers in promoting sustainability helps to overcome negative perceptions of engineering by some. Through the PROPEL center, the creation of the new minor, and the selection of sustainability as the theme of our University's general education committee this year, the concept of sustainability is beginning to permeate our campus.

We recommend that other engineering programs that want to increase multidisciplinarity consider the framework of sustainability as a way to move toward that goal, by increasing the integration of engineering disciplines as well as by increasing the integration of engineering with other fields.

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