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Assessing Achievement of Sustainability Skills in the Environmental and Civil Engineering Curriculum

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Assessing Achievement of Sustainability Skills in the Environmental and Civil Engineering Curriculum

Abstract

Sustainability as a central issue and as a skill set has become an increasingly important part of engineering education for Civil and Environmental Engineers. ABET criteria for both Environmental and Civil Engineering currently contain language stressing sustainability but the development of curriculum components for these degree programs does not yet have an established norm, with some efforts directed at spreading sustainability across the curriculum in a modular fashion within upper level topics and other efforts directed at one, two or three course sequences specifically focused on sustainability. A body of sustainability pedagogy does exist and has been strongly promoted by both AEESP and NSF and is now a topic of discussion by ASCE.

Florida Gulf Coast University was established in the late 1990's as a "green university' as part of the State University System in Florida. The school has environmental sustainability as part of its formal mission in a region acutely sensitive to climate change and dependent on the construction and tourism industries and continuous growth for economic stability in a shrinking and fragile ecosystem.

As part of the original design of the Environmental Engineering curriculum, a Sustainability in Engineering course was established and first taught in the 2008-2009 academic year. The senior-level course is required for Environmental Engineers and serves as an environmental elective for many Civil Engineers. Performance in the senior level Sustainability course varies widely. Good students in both disciplines achieve student learning outcomes at high taxonomic levels. Weaker students in Environmental Engineering also have high outcome achievement. A large cohort of Civil Engineers however, fall short in achieving learning outcomes at the highest levels. This study attempts to assess these differences and improve overall achievement of sustainability skills for Civil Engineering students.

We will use initial survey instruments in these classes as well as in at least one additional Civil Engineering class (sustainability focus included) to assess student attitudes and depth of knowledge prior to and after completion of the Fundamentals of Environmental Engineering course in sophomore year and prior to and after the Sustainability course in senior year. Data has been collected this year (senior level evaluated at end of year) and will continue to be collected over the next several years continuing a longitudinal study that will focus on our students' developing levels of expertise in formulating sustainable solutions to real life engineering problems.

Background

Florida Gulf Coast University (FGCU) is the newest public regional university in Florida. In its mission statement, it is stated that Florida Gulf Coast University emphasizes "innovative, student-centered teaching and learning", "promotes and practices environmental sustainability", and promotes "habits of lifelong learning and the discovery of new knowledge." Established in 2005, the FGCU U.A. Whitaker College of Engineering (WCOE) first admitted students in 2006,

debuting with three majors leading towards the Bachelor of Science degrees in Bioengineering, Civil Engineering, and Environmental Engineering. The Software Engineering Major was added in 2011.

In concert with the University mission, ABET criteria require engineering programs to produce "graduates who pursue life-long learning through continuing education and/or advanced degrees in engineering or related fields. Additionally, ABET criteria 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." (ABET 2014)[1]

With increasing emphasis, sustainability is now recognized as an imperative and in critical need of application in the engineering disciplines, principally in the Civil and Environmental Engineering curriculums. The ASCE Body of Knowledge initiative and Policy Statement on sustainability[2,3] promote the ability to analyze the sustainability of engineered systems and associated natural resources. Lifelong learning is inherent in the principles of sustainability, leading to increasing levels of knowledge and skills required for innovative and adaptive solutions to the problems of sustainable development.[4]

An important focus of sustainability is on the need for engineers to not only practice sustainability but also promote sustainability through sustainable design in their respective field. The American Association of Engineering Societies (AAES) and the World Federation of Engineering Associations state that engineers "strive to comply with principles of sustainable development"[5] and "maintain and continuously improve awareness and understanding of environmental stewardship, sustainability principles and issues related to your field of practice."[6]

To prepare students for future professional practice, FGCU along with many other institutions of learning, has an increased focus on sustainability in engineering with driving forces present to incorporate concepts of sustainability into the undergraduate curriculum. The general topic of sustainability integration in engineering curricula is reflected in many educational studies.[7-14] The reported methods reflect either the vertical integration or horizontal integration of sustainability concepts where vertical integration is the addition of a new course into the curriculum and horizontal integration is the strategy of incorporating concepts into several courses in the curriculum.[15]

Today's engineering graduates face an evolution of global priorities that places an even greater emphasis upon sustainability, community, and well-being. Engineers must be able to develop and adapt current practices to a changing environment. However, traditional engineering programs tend to prioritize and value decontextualized technical content over broad competency development, resulting in students being less aware of the personal and societal value of their engineering activities. Simply requiring one or two courses on sustainability or modules within courses may not change student perception of sustainability. However, problem oriented and project-based engineering coursework applied horizontally throughout the curriculum is an approach that can facilitate deeper understanding of sustainable development and design concepts.[16- 19]

A national level review of the sixty ABET accredited environmental engineering programs showed that few programs exhibit significant curriculum transformation or redesign associated with sustainability concepts.[20] A significant number of programs either do not include any sustainability methodology in their programs or exhibit a weak integration of methodology/concepts in their program. It is important that a detailed approach be taken that strives for specific outcomes associated with sustainability in engineering practice and design. It is equally important that engineering courses integrate sustainability as an imperative, no longer regarding sustainability as external to the technical course content but rather as an essential component of engineering design.

At FGCU, Environmental and Civil engineers share the same course template for the first two years including Fundamentals of Environmental Engineering. By the first semester junior year, all students will have had a first course in Environmental Engineering and Engineering Mechanics and are enrolled together in Fluid Mechanics. Environmental engineers then take courses in water, wastewater, solid and hazardous waste and air pollution control, while Civil Engineers take courses in water, geotechnical, structural and transportation topics. The senior-level course in Sustainability is required for Environmental Engineers and serves as an environmental elective for many Civil Engineers.

Upper level courses in Environmental Engineering incorporate project- based assignments that incorporate principles of sustainability (Table 1) as defined at the Sandestin Conference as the "Principles of Green Engineering" and further developed as the Principles of Sustainable Engineering.[21]

Table 1. Principles of Green Engineering[13]

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life-cycle thinking in all engineering activities
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions

For example in the Environmental Engineering course in Atmospheric Pollution, students have completed projects titled "Cleaner, Greener Fireworks" and "Coal Combustion and Sustainability", and the "The Military Fires at the Atmosphere" all with an emphasis on reduced pollution and minimal use of resources.

For the senior level course in Sustainability, students complete projects on a variety of sustainability concepts including;

- Solar power at FGCU
- Energy usage in student housing
- The FGCU CO_2 footprint
- Campus water usage
- Hazardous waste disposal on campus
- Sustainability as related to commuting and time management on campus
- Solar carports
- Electric buses
- Paper waste on campus

Because of this new imperative for sustainable design in engineering, the curricula is now being evaluated to determine just how prepared students are to practice sustainable design. Currently, only the Atmospheric Pollution and Sustainability courses incorporate the project-based approach aligned with the principles of sustainable, "green" engineering. Therefore, the first stage of this longitudinal study is initially to evaluate current student knowledge of sustainability and expertise given present curricula and course content. Then, through continuing curriculum-wide course integration of sustainability concepts, we will continue to assess more fully our students' progress in sustainable skill sets, enabling an evaluation of differences in Environmental and Civil student outcomes. Since this is the first year of assessment in our programs, we will evaluate students' sustainability knowledge as new course designs are introduced and implemented in the curricula.

Initial background survey

For the initial background survey, questions were formulated with the help of a literature search.[22-24] The purpose of the survey was to assess student knowledge of sustainable practice and to identify variables including engineering major (Civil or Environmental or Dual), years of study, student interest and knowledge of environmental issues and policies.

At the start of the survey students read the following: "We are asking for your help in learning more about the level of understanding and knowledge that undergraduate students have regarding the environment and sustainable development. The results of this survey will help us to improve the existing courses and develop new teaching programs related to this area. Please respond to the following items as honestly and carefully as possible".

Student gender and years of study are then entered with the survey itself organized into the following sections:

1. Environmental Issues
2. Environmental Legislation, Policy and Standards
3. Environmental Tools, Technologies and Approaches
4. Sustainable Development

The survey questions are listed by question and shown in Tables 2 -5. These questions are then ranked by students on a 4 point scale as follows:

1. – not heard of
2. – heard of but cannot explain
3. – have some knowledge
4. – know a lot

The students are also asked to rate the importance of sustainable development 1) as a person, 2) as an engineer, 3) for your country, 4) for global society and 5) for future generations. In addition, students indicate if they had any environmental education in school in general and in particular in their university courses. The survey questions specific to the importance of sustainable development are ranked on a 4 point scale as follows:

1. Not important
2. Possibly important
3. Important
4. Very important

Table 2. Topics: Environmental Issues (Survey section 1)

Acid rain
Air pollution
Biodiversity
Climate Change
Deforestation
Depletion of natural resources
Desertification
Ecosystem Services
Emerging Pollutants
Global warming
Hazardous waste
Ocean acidification
Ozone depletion
Photochemical smog
Planetary Boundaries
Pollution Prevention
Renewable Energy
Salinity
Solid Waste
Water pollution

Table 3. Environmental Legislation, Policy And Standards (Survey section 2)

Intergovernmental Panel on Climate Change
United Nations Environment Program (UNEP)
Kyoto Protocol
Resource Conservation and Recovery Act (RCRA)

Clean Air Act (CAA)
Clean Water Act (CWA)
Superfund
United Nations Sustainable Development Goals

Table 4 Environmental Tools, Technologies And Approaches (Survey section 3)

Benchmarking
Clean Technologies (for example carbon capture)
Remediation technologies
Design for the environment
Eco-labelling
Industrial ecology
Life cycle assessment
Product stewardship
Renewable energy technologies
Resiliency
Tradable permits (emissions permitting, cap and trade)
Waste minimization
Energy Auditing
Geo Engineering
Fracking/Pollution Control

Table 5 Sustainable Development (Survey section 4)

Sustainable development, definition and concept
Components of sustainable development
Approaches to sustainable development
Precautionary principle (GMOs, for example)
Population growth
Inter and intra-generational equity
Stakeholder participation
Connections between poverty, population, consumption, degradation of environment
Earth's carrying capacity
Social responsibility
Engineering community's response to sustainable development
Actions taken by companies and engineers to promote sustainable development.
Energy-Water-Food Nexus

Table 6.Importance of Sustainable Development to:

You personally
You as an engineer
Your country
The society world-wide
Future generations

Results and Discussion

To date, 105 responses (n=105) have been collected through the online survey, including students enrolled in Fundamentals of Environmental Engineering (typically taken by sophomores), Atmospheric Pollution, Hazardous Waste Remediation, Sustainability in Engineering and Structural Analysis at FGCU. The response rate to date for the online survey is 51% for students enrolled in these 4 courses. Fourth year students take Atmospheric Pollution and Sustainability courses with third year level students enrolled in Hazardous Waste and Structural Analysis. The initial year survey differentiates response by years of study (not by student level).

Figures 1-5 show each survey item (listed in tables 2-6) with mean response grouped by major.

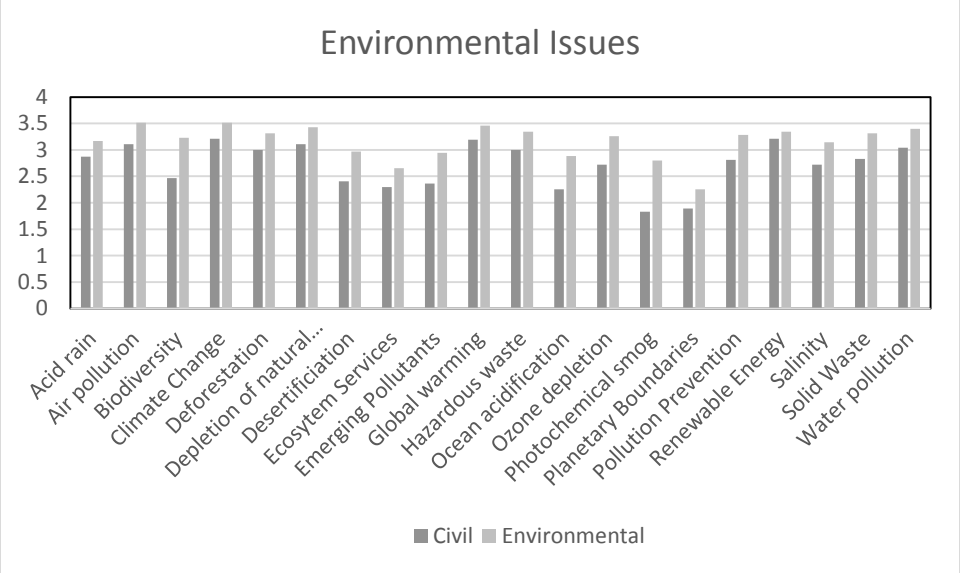

Figure 1. Mean response on survey questions grouped by major

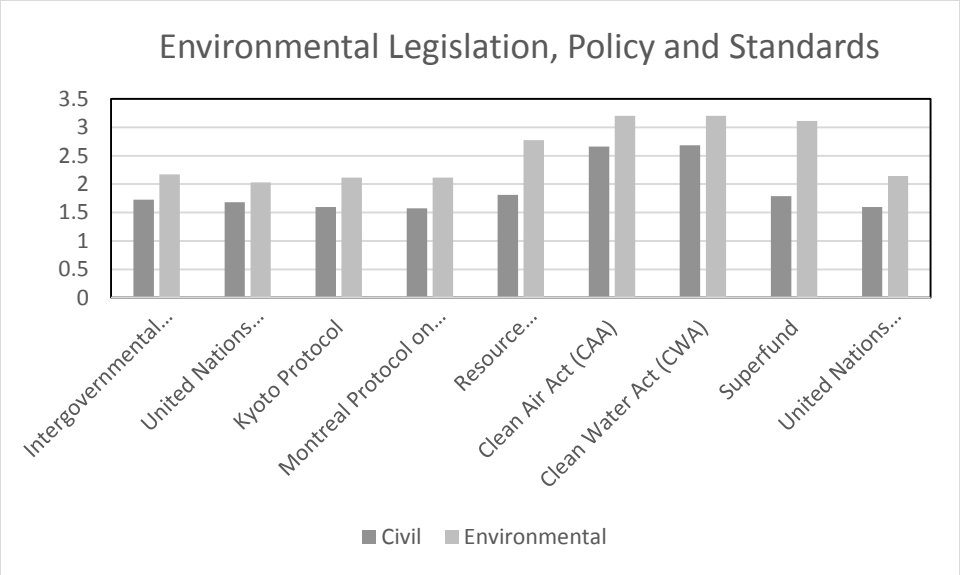

Figure 2. Mean response on survey questions grouped by major

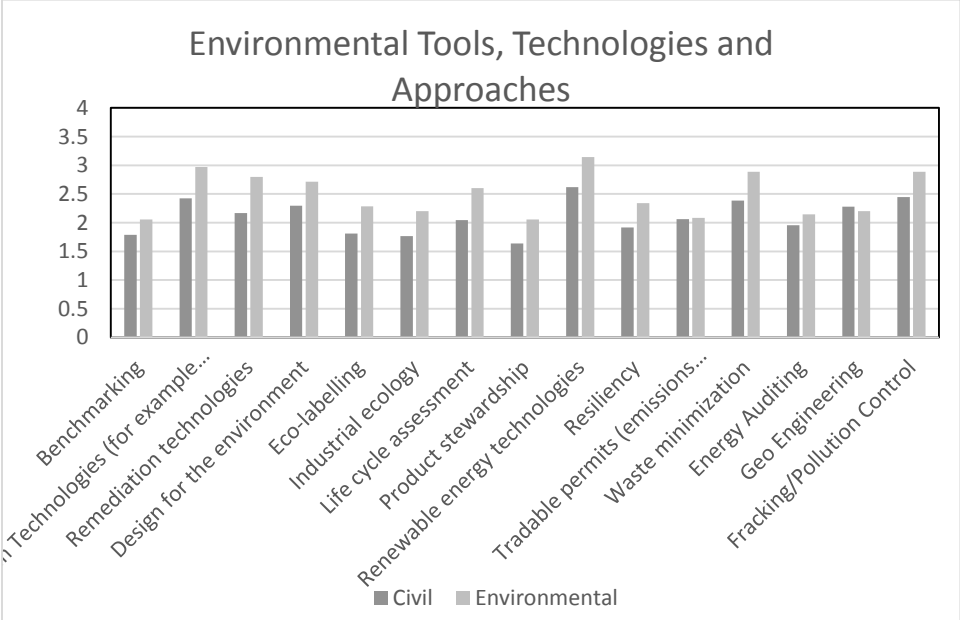

Figure 3. Mean response on survey questions grouped by major

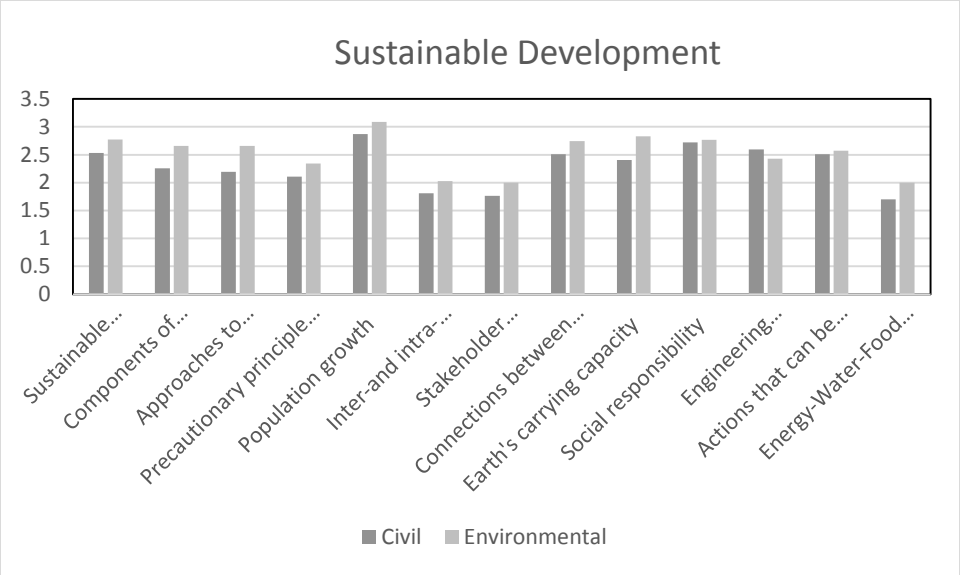

Figure 4. Mean response on survey questions grouped by major

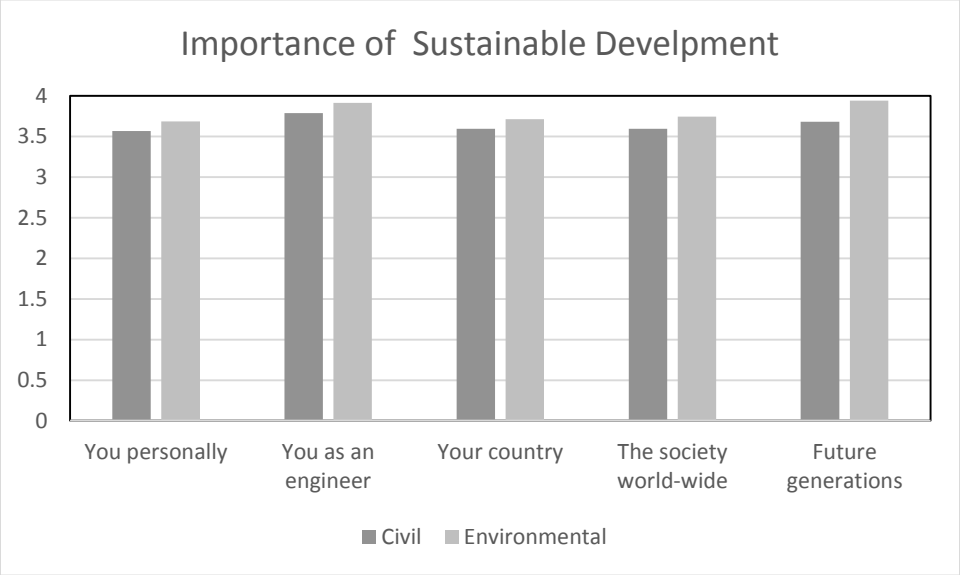

Figure 5. Mean response on survey questions grouped by major

The Environmental Issues section shows consistently higher ranked responses for environmental engineering students (Figure 1; Table 2 - Section 1) with both majors exhibiting weak knowledge on Environmental Policy except for environmental student knowledge of the CAA, CWA, RSRC and Superfund (Figure 2; Table 3 – Section 2). For responses on Environmental Tools, Technologies and Approaches (Figure 3; Table 4 – Section 3), there are weak areas present for both civil and environmental students on most topics except for better environmental student knowledge of clean technologies, renewable energy, waste minimization and fracking/pollution control. Responses on sustainable development topics (Figure 4; Table 5 – Section 5) are mostly weak for both majors (<3, heard of but cannot explain). However on

the final section, where students rank the importance of sustainable development 1) to them personally, 2) as an engineer, 3) for your country, 4) for society world-wide, 5) for future generations, the average for both response majors is >3.5 (very important).

It is clear from this initial survey that environmental engineering students appear to have stronger knowledge of sustainability topics, but there exist many areas of weakness in both majors. A clear result is that virtually all students, regardless of major, rank sustainable development highly in terms of importance to themselves and the future. Considering the high importance surveyed students give sustainable development along with the imperative to achieve sustainable growth, the case is ever more compelling for integrating sustainability concepts and design modules across the curriculum. Student awareness and understanding of environmental stewardship, sustainability principles and issues related to their field of practice must be continually updated and enhanced as the challenges to sustainable development ever increase locally and globally.[25-27]

To address these weaknesses and deepen student understanding, we will implement project-based learning curriculum-wide that includes an emphasis on sustainability concepts. In the capstone Engineering Senior Design Course, sustainability in design will be assessed at the end of this term with a continual long-term assessment of sustainability knowledge. Our senior design assessment results will provide a view of our progress in implementing sustainability principles and practices curriculum-wide, given our current proposed strategy of incorporating concepts into several courses across the curriculum.

Conclusions

Initial survey results confirm that FGCU students consider sustainable practices and development of great importance to themselves and future generations. Currently a project-based approach to promoting student knowledge and skill in sustainability design is limited to upper level environmental engineering courses. The long-term goal is to introduce sustainability-related activities and projects throughout the curricula and to assess levels of expertise in sustainability as students progress towards graduation.

This longitudinal study will attempt to elucidate differences between Civil and Environmental teaching strategies implemented to integrate sustainability concepts in course delivery. Continual assessment will help identify more effective teaching methods and yearly senior level capstone design course assessments will evaluate student skill in applying sustainability in engineering practice and design.

An expected outcome of this study is the identification of innovative and effective teaching strategies for development of student skills in sustainable engineering practice. Vertical and horizontal integration of sustainability concepts will be compared in engineering curricula. The intrinsic motivation of students to practice sustainability in design requires an integrated approach that will address student preconceptions of sustainability in the early stages of engineering coursework. The implementation of study results will promote student knowledge and expertise in sustainability practices as sustainability concepts are continually incorporated and updated in Civil and Environmental engineering coursework.

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